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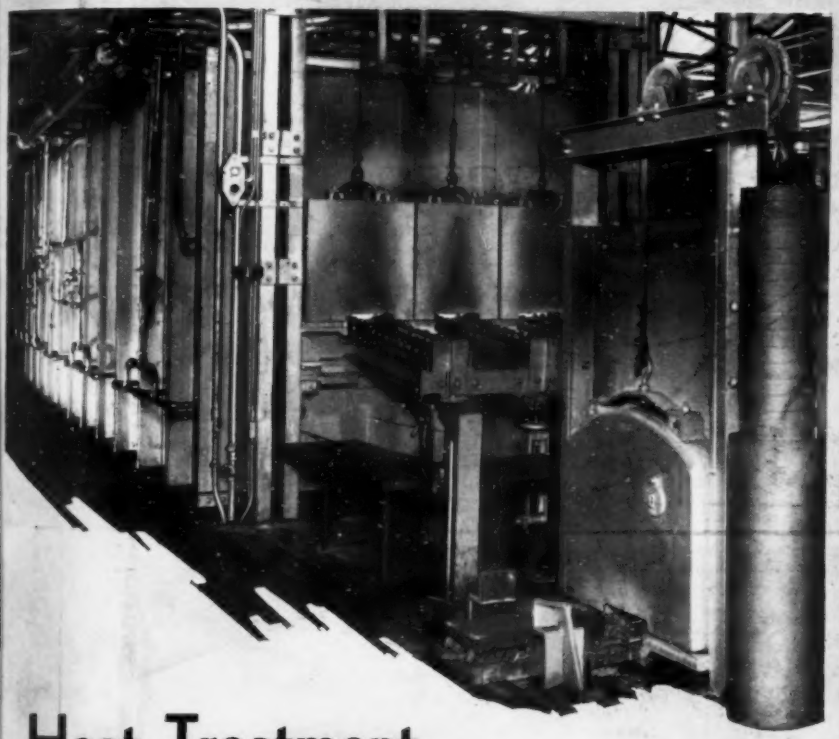

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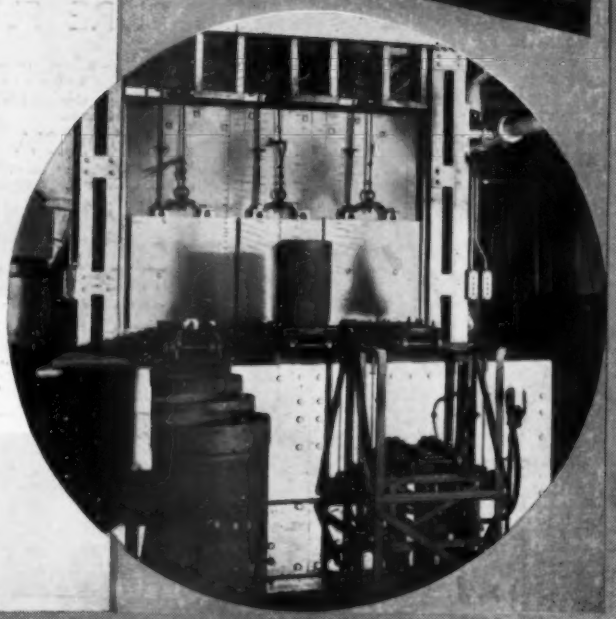

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The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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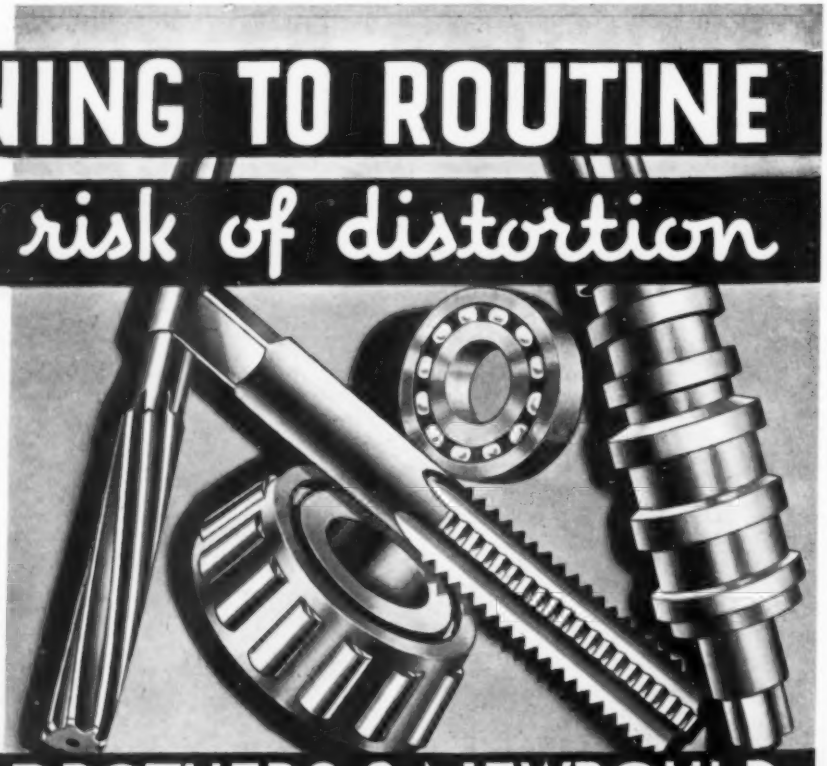

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DECEMBER, 1940. VOL. XXIII, No. 134.

Tin and Industry in 1940

(Contributed by THE TIN RESEARCH INSTITUTE.)

Certain unique characteristics of tin make it almost indispensable for certain industries, and this review briefly discusses improvements and advances in all important forms in which it is used. Particular attention is directed to production and changes brought about by war.

OWING to the political grouping of the various tin-producing countries and to their geographical disposition, the war throughout 1940 has interfered less than might have been expected between suppliers and their chief markets, in the British Empire and America respectively. The International Tin Committee which regulates production to ensure a reasonably stable market was formed by the Belgian Congo, Bolivia, French Indo-China, Malaya, the Netherlands East Indies, Nigeria, and Thailand; and although France, Belgium and Holland are now dominated by Germany and all contact with them has been cut off, British contact with their overseas empires has been strengthened.

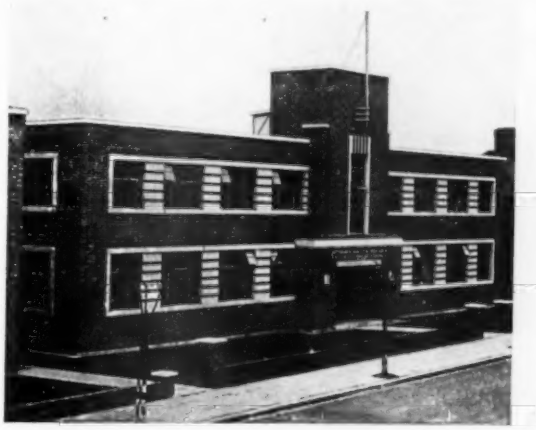
The tin which formerly was smelted in Holland is now smelted in British Malaya and the Netherlands East Indies; part of the tin ore produced in the Belgian Congo is smelted locally, and part is shipped to England. The outputs of Bolivia and Nigeria are also smelted in England.

At the outbreak of war the production quotas sanctioned for the countries signatory to the International Tin Agreement were only 40% of the standard tonnages. (Outputs corresponding to 100% quotas are the following: Malaya, 77,335 tons; Bolivia, 46,027; Netherlands East Indies, 39,055; Thailand, 18,628; Belgian Congo, 14,035; Nigeria, 10,890; and French Indo-China, 3,000 tons.) To ensure an adequate supply of tin outside enemy territory, the quota for the third quarter of 1939 was fixed at 120%, and for the fourth quarter, 100%. In 1940 the quotas for the first two quarters were respectively 120% and 80%.

Following an agreement between representatives of the International Tin Committee and of the United States Government, the quota for one year from July 1, 1940, was fixed at 130%, to provide for the accumulation in America of a reserve stock of 75,000 tons of tin.

During the first twelve months of the war, 100,730 tons of tin were delivered to the United States, including a contribution towards the reserve stock. The peace-time tin consumption of the U.S.A. was around 70,000 tons annually, of which 35,000 to 40,000 tons were used by the tinplate industry; 11,000 tons for solder; 4,000 tons for bearing metals; 4,000 tons for bronzes; 3,500 tons for collapsible tubes; 1,500 tons for tinfoil, and the balance for tinning, type metal, pewter, fusible alloys, and other uses.

The average annual consumption of tin in the United Kingdom during the five years before the war was 21,725 tons. The consumption during the first year of war was 33,200 tons, from which it appears that the war has increased consumption above peace-time needs by some 11,500 tons. The production of tinplate in the United Kingdom is no greater than in peace-time, but is, in fact, restricted by the diversion of steel to other uses as well as by official restrictions on the use of tin cans. The directions in which the consumption of tin has increased are those which are directly concerned with the country's war effort,



The Tin Research Institute's building at Frazer Road, Greenford, Middlesex.

such as solder, bearing metals, bronzes, hot-tinning and electro-tinning.

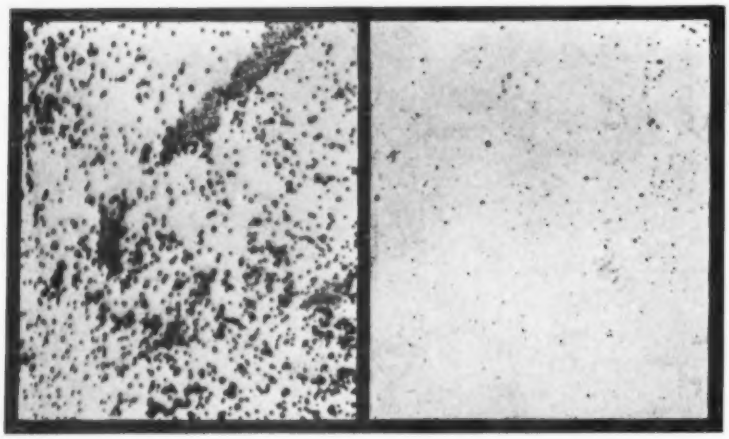
The same countries which combined to regulate the production of tin also formed the International Tin Research and Development Council. This body has continued to function actively, and its organisation at Greenford, Middlesex, has now been established as the "Tin Research Institute."

The Council's Statistical Office, which had its headquarters in The Hague, ceased to function when Holland was invaded, and since May, 1940, statistics of production, consumption and stocks, so far as they are available, have been collected and disseminated from Greenford.

The scope of the work at the Tin Research Institute has been affected by loss of contact with consumers on the European continent and by war-time conditions in England. At the outbreak of hostilities work on long-range researches was stopped, and the programme reorientated to allow concentration on uses of tin in war-time industries. These are, however, fundamentally similar to peace-time uses, and apart from the activities of the technical information section, an unexpected continuity has been possible in certain lines of research.

Tinplate

The Institute's experimental tinning machine devised some year ago, on which a number of improvements have recently been made, has shown that a smoother and less porous coating than is now commercial practice can be obtained on tinplate without increasing the weight of tin used. On ordinary tinplate the coating has slight ridges and valleys running both along and across the sheet. The new tinning machine greatly reduces these inequalities, and



Result of porosity test (left) on ordinary tinplate and (right) on tinplate after 5 minutes' treatment in the new filming solution.

An example of hot-dip tinning, which is widely used to produce protective coatings on cast iron, steel, copper and brass articles.

as porosity is naturally more prevalent where the coating is thin greater uniformity gives reduced porosity.

Hot-tinning

In this war, as in the last, there has been a considerable increase in the demand for hot-tinned work. The dearth of experienced tinners, and the many new firms entering the business has stimulated a large demand for information and advice. As the result of the work done over the past few years, it is possible to cope with most of the demands, and practical demonstrations of hot-tinning are given each week at the Institute to all who are interested in using this process for war contracts. Help has been given in starting up and running tinning baths, and investigations carried out in cases where special difficulties have arisen. The hot-tinning of cold-rolled strip sometimes presents special difficulties, which appear to be connected with the type of rolling lubricant used and with the annealing conditions. This has been studied and steps which overcome the difficulty can now be recommended.

To make the available information readily accessible, the subject of hot-tinning has been dealt with exhaustively in a book which will be ready for distribution before the end of the year.

Protective Films on Tinplate

A great deal of tinplate is used for packing foodstuffs, many of which contain sulphur compounds, as, for instance, meat, fish, peas, etc. If unprotected tinplate is used chemical action arises during the hot sterilising process and even during storage, especially in summer time or in tropical latitudes. The tinplate develops black markings and in certain cases even the foodstuffs may be stained. In some cases, but not all, the difficulty can be overcome by using a sulphur-resistant lacquer, but the new filmed surface developed by the Institute has many attractions.

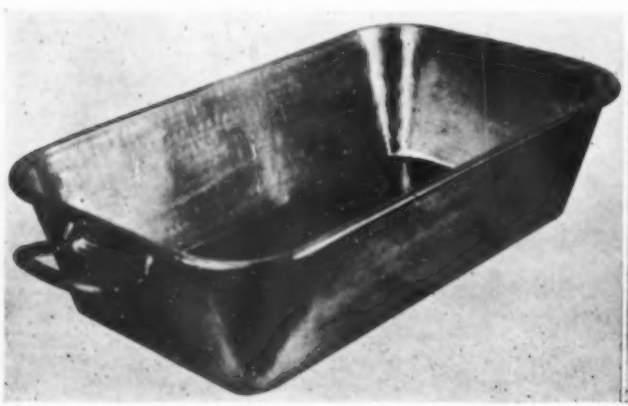
The process consists in immersing the tinplate or the empty can in a hot solution of a chromate, in the presence of an alkaline detergent and a suitable wetting agent. After a few minutes a thin and quite invisible film is formed and a thorough rinse completes the process. The film has been found to give complete protection with many sulphur-bearing foodstuffs. The process is cheap and relatively easily adapted to commercial canning conditions, and large-scale tests are now under way in more than one cannery.

Electro-deposition of Tin

At an earlier stage the work of the Institute was directed to determining the relative merits of the various plating solutions known, and to determining the exact conditions to obtain the best possible coatings. This work was summarised in "Electro-Tinning (Working Instructions)." Numerous plants are now running on the lines laid down, and it may be said that tin-plating is now an ordinary industrial process. Some difficulty arises through the existence of earlier and quite unreliable processes, chiefly the sodium stannite bath, which is still sometimes recommended. The use of steel equipment heavily tinned by combined hot-dipping and electro-deposition is increasing in factories handling food products. Electro-tinning not

This vessel, used in the meat-processing industry, has been reconditioned by electro-tinning. Coatings of any desired thickness can be applied by this method, providing a greater degree of protection than can be obtained by hot-tinning, with a corresponding increase in the time before retinning becomes necessary.

These cans were packed with corned beef and opened after three months' storage. The stained can was of plain tinplate. The other can had been given a protective surface by the Tin Research Institute's new process, and remained as bright as when originally packed. Similar results have been obtained with other food products.



only cheapens the retinning cost, but as it provides a thicker coating than has hitherto been available it offers opportunities for economy that are now being appreciated.

White Bronze

The electro-deposition of this interesting alloy has made some progress in industry. The coating, although almost indistinguishable from silver, has an attractive warmth of colour and a somewhat unexpectedly high resistance to tarnish and corrosion. The alloy consists of about 40% of tin and 60% of copper, and is, indeed, the speculum metal of the ancient world. When our industries return to peace-time conditions the coating will be widely adopted for domestic hardware and decorative metal work.

Bearing Metals

With the higher speeds and compression pressures used in the latest designs of internal combustion engines, bearing pressures have tended to rise above the safe load for babbitts. This has been met by attempts to improve the strength of the white metal and by the introduction of other alloys which, although poorer as anti-friction metals, have sufficient strength for the new running conditions. The unique features of tin-base bearing metal are: Its ability to retain its oil film; its freedom from scoring and from liability to seize. For these reasons even a moderate improvement in mechanical qualities would justify its restoration almost universally. Some progress has been made by using thinner babbitt shells, which permit the mechanical strength of the backing metal to play a greater part, but chief interest centres on certain new alloys developed during the year which are now undergoing extensive trial in conjunction with bearing metal manufacturers and engine builders. Like the original babbitts, these alloys contain over 90% of tin, but the additional elements have been varied and alloys have been obtained of substantially greater mechanical strength and with the capacity for retaining a larger proportion of that strength at the relatively high-working temperatures now in use. A valuable feature is that the enhanced mechanical properties have not been obtained by any sacrifice of the anti-friction qualities. The results of the practical tests are awaited with interest.

Other work includes the discovery of an improved pewter alloy of about twice the strength of the alloy now in use. Improved methods of casting bronze are also being developed which permit the use of a higher tin content and provide alloys with greatly improved mechanical qualities and corrosion resistance.

In summary, it may be said that such improvements and advances are being made in all the important forms in which tin is used as will enable it at least to hold its own in these times of rapid metallurgical progress.

Microhardness of Metals in Thin Layers

A new diamond indenting instrument has been developed for measuring the indentation hardness of brittle materials. Reference is made to this instrument in its application to the hardness determination of thin layers of metals.

A SENSITIVE diamond indenting tool has been developed recently at the National Bureau of Standards in the United States for measuring primarily the indentation hardness of brittle materials, such as glasses, crystals, and enamels, which shatter when tested with the ball, cone, or square base, pyramid tools commonly used on metals. Using this new instrument for determining the microhardness of thin layers of metals, C. G. Peters and F. Knoop* have made a series of hardness tests on a number of metallurgical materials to show its unique applications. Some of these were determinations of the hardness of the nitrided skin on molybdenum high-speed steels, with different times and temperatures of salt-bath treatments; the hardness of large carbide particles in high-speed and plain carbon steels; the hardness of sintered carbides including boron carbide; and the hardness of a number of other materials including chromium plate and phosphor bronze sheet.

The indenter, which is of pyramidal form, having a diamond-shaped base, is a diamond crystal of 0·25 to 1·5 carats, rigidly mounted in a metal holder for cutting and use, and having a length approximately seven times its width and 30 times its depth. It is shown on the left of Fig. 1; the shape of the indentation being shown on the right. The sensitivity of this tool is such that a load of 0·5 kg. gives for hard steel indentations of 100μ length which can be measured with an accuracy of 1 μ with a micrometer microscope, and it is evident from the magnitude of the penetration which is but 3 μ for an indentation of 100 μ length, that very thin metal specimens may also be tested as well as brittle materials. The indentation or hardness number I is the ratio of the load L in kilograms applied to the indenter, to the unrecovered projected area A in (mm.)²

$$I = \frac{L}{A} = \frac{L}{l^2 C}$$

where l is the measured length in mm. of the long diagonal of the indentation, and C is a constant relating l to the projected area. In making indentation tests, the indenter is incorporated with a device for applying a known load and with a micrometer microscope in a single unit, and the indentation number corresponding to a measured length l and a given load is read from a chart.

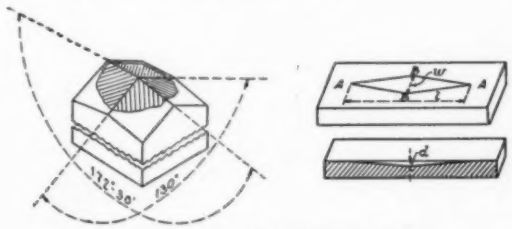


Fig. 1—Diamond indenting tool.

For testing chromium plating, nine steel blocks 0·9 in. diameter, 0·5 in. thick, with surfaces polished plane to about 0·00001 in. were plated with different thicknesses of chromium deposited at different current densities. Indentations were made on each block under loads ranging from 50 g. to 2 kg. For platings of 0·001 in. or more in thickness, the hardness seemed to be unaffected by the hardness of the basis metal. Different current densities gave about the same results, although if anything, the lower density seemed to produce a slightly harder deposit. The ratio of the deposit thickness to the depth of penetration had a marked effect on the hardness number, and wherever that ratio became less than 14 for the heavier load, a marked falling off of the hardness ensued, and from this it was considered that to obtain consistent results, the deposit thickness should be at least 14 times the depth of penetration of the indenter.

Nine specimens of commercial phosphor bronze containing 95% copper, 4·6% tin, and 0·2% phosphorus rolled to thicknesses of from 0·002 to 0·008 in. were tested from 50 g. to 500 g. As in the case of chromium plate, the thin samples of phosphor bronze gave low hardness numbers,

* *Metals and Alloys*, 1940, Vol. 12, No. 3, pp. 292-297.

and for the heavy loads the numbers decreased for thicknesses of 0·006 in. or less. With the 0·002 in. specimen no difference was found for indentations having their long diagonal parallel and perpendicular to the direction of rolling. A decided softening was produced by heating the 0·004 in. and the 0·006 in. specimens to 400° C., when the ratio of the necessary thickness to the penetration was about 35 as against 25 for the other specimens.

One annealed and one hardened specimen of molybdenum-tungsten cobalt steel, and one specimen of hardened molybdenum-tungsten high-speed steel which had been nitrided by immersion for two hours in a bath composed of 50% KCN and 50% Na C N at a temperature of 550° C. were also tested. The hardness numbers obtained for the carbides of the first two specimens were approximately the same, but the hardness of the matrix in the hardened specimen was more than three times that of the matrix in the annealed specimen. In the third specimen hardness determinations were made from the edge inwards, and the maximum hardness was found at a depth of 10 to 20 μ. Beyond 20 μ the numbers decreased until they became constant at the matrix value for depths greater than 60μ, showing that the effect of the nitriding reached a depth of about 0·002 in., and was a maximum to a depth of 0·001 in.

Determinations were also made on specimens of nitrided high-speed steel. Some were annealed and some hardened before nitriding for different lengths of time, others were tempered before nitriding for different lengths of time and before nitriding at different temperatures, and four samples were hardened before nitriding at different temperatures. The data obtained from these tests showed that the final hardnesses of the hardened specimens were much higher than those of the annealed specimens, but that the increase in hardness produced by the nitriding was greater for the annealed specimens. Lower hardness numbers were obtained for thin layers and heavy loads an effect similar to that found for thin plating and rolled sheets. Data from the hardened and the tempered tests showed that nitriding for about 90 min. near 600° C. produced the maximum surface hardness.

Indentations made on a metallographic specimen of a high-purity iron carbon alloy gave hardness values ranging from 190 for soft pearlite to about 720 for fully-hardened martensite. A nodule of troostite 25 to 30 μ in diameter had a hardness number of 570, whereas the surrounding martensite had a value of about 700. Determinations of hardness were also made in the coarse grain of lamellar pearlite both transversely and in the direction of the laminations, and showed that the pearlite grain was apparently softer in the direction of the laminations.

Indentation numbers were also determined for standard Rockwell specimens and for rolled copper with the pyramidal indenter and with the Brinell and Vickers hardness machines. The results obtained were as follows:

Specimen.	Ball.	Load, (2,000 kg.).	Brinell Hardness.	Vickers Hardness.	Indentation Number I.
Rockwell C 65–67 ..	10 mm. Carbaloy ..	3,000	780	894	791
Rockwell C 47 ..	10 ,, ,, ..	3,000	456	493	486
Rockwell C 25 ..	10 ,, ,, ..	3,000	241	265	276
Rolled Copper ..	$\frac{1}{8}$-in. steel	15	104	111	123
Rockwell B 7–9 ..	10 mm. steel	500	52·8	58·2	59·2

These data show that the indentation number I obtained for rolled copper is 20% greater than the Brinell hardness number, and 30% greater than the corresponding Vickers number, while the indentation number for steel C65–67 agrees with the Brinell hardness, but is 12% less than the Vickers hardness for the same steel.

Hardness numbers determined by the indenter for minerals of the Mohs scale and for several hard abrasive materials showed a big gap to exist between the hardest carbide and the diamond, average values of 8,350 2,250, 2,100, 1,625 and 1,250 being obtained for the diamond, moulded boron carbide, black silicon carbide alundum, and carbaloy, respectively. The extremely high force exerted by the minute point of the diamond tool in making the indentation in these hard materials can be appreciated when expressed in pounds per square inch. For hardened steel the pressure was computed to be over 1,000,000 lb. per sq. in., for mould boron carbide over 3,000,000 lb. per sq. in., and for the diamond about 12,000,000 lb. per sq. in.

Manganese Production in the Urals

A New Manganese Centre

A NEW manganese-producing centre is being established in the North Urals. Preparations are now far advanced for the construction of a big combine early in 1941. The district in which the combine will be built—near the village of Polunoch in the Ivdel Province—contains one of the largest manganese ore deposits in the Soviet Union. The preliminary survey of the route for a new railway running from Ivdel to the manganese deposits has already been completed.

The new manganese centre will obviate the need to transport manganese ore from the southern parts of the Union. Until the discovery of the Ural fields, deposits of manganese in Russia were concentrated in the Ukraine and in Georgia, and the ore had to be transported for thousands of miles to the Urals and Siberia.

Porosity and Analogous Problems in Aluminium Alloy Castings

CONDITIONS and factors making for porosity in castings apply more or less to all metals, but in a recent booklet* reference is made especially to aluminium alloy casting. These factors include the composition and initial condition of the alloy to be used; the procedure adopted for melting; the care exercised in the rate of heating; temperature control; the time the metal is held in a molten state; technique of pouring; the type of mould; and the size and design of the casting. In addition, the chemical, physical, and mechanical properties of aluminium alloys confer, to some degree, special features upon the various forms of porosity and analogous defects which in the cast form may occur in them. These special features, in the case of light alloys, are low specific gravity, which reduces the resistance to the tendency of mould gases to blow back; the comparatively low-casting temperatures; hot shortness of many of the alloys; and pronounced casting shrinkage. In spite of these many factors, progress in foundry technique has reduced the number of faulty castings to a comparatively small percentage of the total.

Particular reference is made to the influence of alloy composition on soundness, and mention is made of the types of alloys that are easy to cast, and also of those which present special difficulties. The initial state of the metal to be melted and cast is considered and melting practice is discussed, particularly in relation to the tendency of light alloys to absorb gases, and the elimination of moisture and prevention of contact with combustion products are both directed to reducing the amount of gas absorption. Overheating must be avoided, and the optimum casting temperature for the particular alloy composition, and size and design of casting, adhered to. Suitable means for removing gases from the melt are discussed, and the mould design in relation to soundness is considered. The importance of the right type of moulding sand is stressed, and reference made to the design of dies for gravity and pressure die-casting. Means for eliminating recurrent defects are also considered in relation to the method of examining castings by means of X-rays, and the use of pressure tests, of which the former can be used to provide guidance in obtaining soundness in castings.

* "Aluminium Technique," issued by Aluminium Union, Ltd., The Adelphi Strand, London, W.C. 2.

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INCORPORATING "THE METALLURGICAL ENGINEER"

British Metallurgical Progress in War-Time

WAR is always an evil, and because of its magnitude the present war has caused tremendous commercial and industrial dislocation. It has thrown world industry into the crucible, but it is remarkable how British industry has applied itself with continuously increasing vigour to the enormous demands made upon it, especially when it is remembered that it is now in the front line and bearing its share of the knocks that in war are normally taken by the armed forces. There has been great activity in all the metallurgical industries during the past twelve months, and when production figures become available, it will be found that in all sections output records have been established. In many respects this is not surprising, because, since the outbreak of hostilities and especially since the fall of France, Britain and the Empire has been engaged in a life-or-death struggle, and it has been incumbent upon the industries to make every effort to supply the growing needs of the Services. In addition, however, the necessity of maintaining our export trade at a high level, has contributed in no small measure to the high outputs achieved.

In total war, such as this in which we are engaged, British industry is concentrated upon special war efforts that not only concern the production of vast quantities of arms and ammunition, but all the plant and machinery to satisfy the demands of the Forces, and, indeed, intensive activity in all the basic industries to effect an early satisfactory conclusion to hostilities. We are dependent upon transport from overseas for food, materials, machinery and merchandise essential to the successful prosecution of the war and the concentration on shipbuilding to replace losses in action has made great demands on the metallurgical industries. The various branches of engineering, too, have been very active during the year, particularly marine and electrical engineering. The latter, in addition to meeting the essential needs of the home market, has been vigorously engaged on work for overseas. In this connection mention may be made of important new orders covering a complete new power station of 60,000 kw. capacity for Turkey. Thus, it will be appreciated that production in the metallurgical industries on a vastly increased scale has been a necessity, but the high levels attained would have been impossible of accomplishment without the aid of many and varied contributory factors.

Whether at peace or war, Britain is dependent upon its iron and steel industry. Despite developments with other materials, the ferrous metals are of supreme importance, and an efficient iron and steel industry is of vital concern. For some years after the last war the British iron and steel industry as a whole was in distress ; it had been left with a surplus of plant, either obsolete or in need of improvement, while the evils of cut-throat competition and under-employment of this plant added considerably to the economic difficulties. Since that time, however, it has been completely reorganised. Extensive developments had been in progress for many years, and at the beginning of the present war the iron and steel plants had been modernised or entirely reconstructed and were in a position to augment greatly their output. The full results of the considerable capital expenditure involved were not then possible, but since the beginning of this war they have been working to capacity, and there is ample evidence that they are producing as efficiently and as economically as the most modern plants elsewhere. As will be appreciated, the change from peace to war conditions involved some dislocation, and the task of adjusting production to priority demands necessitated considerable co-ordination of effort to augment output for war purposes. With the increasing need for intensified production there is no doubt that attention will also be given to the co-ordination of effort in eliminating forces retarding production with a view to raising further the standard of efficiency of this vital industry, and thus enable it to improve upon its present achievements.

It is well to remember the almost illimitable resources of the British Commonwealth of Nations in non-ferrous ores and that supplies of these essential materials arrive in Britain with such regularity that plants are able to operate at full capacity. Non-ferrous metal smelting and refining ranks first among Canada's manufacturing industries and the war has given a great impetus to her mining industry ; it is safe to say that new high-production levels are now being attained in Canada to meet the requirements of Britain. But this is also true of Australia, from which Britain has purchased all the exportable surplus of Australian copper, zinc, lead and tungsten. The surplus of New Zealand wolfram, too, has been purchased by Britain, and the same applies to the non-ferrous base metals mined in South Africa and Southern Rhodesia. Normally, neither Britain nor the Dominions exercise a monopoly of these resources, which would be detrimental to the rest of the world. In peace-time they are available to other nations on the open market at world prices, but, in war-time, they have become a vast reservoir upon which the members of the Commonwealth can draw, and which are denied the common enemy. But, while a considerable amount of smelting and refining is carried out in the Dominions and the ingots and slabs shipped to this country, there are aluminium and magnesium-producing plants in Great Britain that are the last word in modernity, tin, zinc and copper refineries that are thoroughly up-to-date and in many aspects are unsurpassed anywhere.

There has been tremendous research activity during the twelve months, and in the metallurgical industries this has been directed more especially to the elucidation of current problems rather than to the development of new alloys, although it must not be assumed that no work in the latter direction is in progress, because a number of new and modified alloy steels for specific purposes have been tested and found to possess admirable properties, and to be in some respects superior to existing alloys developed for similar purposes. It is not possible however, to discuss in any detail the valuable scientific and technical work carried out or in progress since the outbreak of war, but it is sufficient to remind ourselves that the immense activity of the metallurgical industries is supported by persistent research, the results of which enable our aircraft, naval and merchant vessels, and all the plant and machinery essential to war conditions, to give the utmost service, however arduous the circumstances.

With few exceptions, the various British ferrous and non-ferrous materials, which are proving so successful under war conditions, are just as applicable for service under peace conditions and the intensive work involved in perfecting production will ultimately secure for British industry a foremost position in the markets of the world.

Secondary and Scrap Aluminium

UNDER this heading we published an editorial in our August, 1940, issue, in which we stressed the need for conservation of metals. It was emphasised that, while attention must be given to safeguard supplies of strategic minerals, the stock of metal in use is no less a valuable resource than unmined ore. It is frequently assumed that conservation is concerned only with the production phases of the metal industries, whereas the effective conservation in the utilisation phases is, at least, as important. It should not be overlooked that real conservation can be achieved by promoting the constant use and re-use of that part of production which is not destroyed in service. Thus, the recovery of scrap and wastes, and their use with or instead of metals produced from ores, is sound economics, and entirely in accordance with the general principle of conserving natural resources. This principle is recognised in all the metal-producing industries. In the iron and steel industries, for instance, the use of scrap has become essential in certain steel manufacturing processes, and it is regularly used in iron and steel foundries, but for some unaccountable reason the re-use of aluminium in this country seemed to be discouraged. We are glad, however, to publish elsewhere in this issue the information from Mr. H. F. James, director of Northern Aluminium Co., Ltd., that steps have been taken to ensure that all good quality scrap is recovered in an identifiable form for further use.

The recovery of aluminium from scrap of various kinds and its use with or instead of virgin metal is sound economics. Difficulties are undoubtedly encountered in maintaining the high grade of secondary aluminium suitable for re-use under present conditions, but with care and experience in sorting scrap into various categories these difficulties should not be insurmountable. If clean, carefully graded scrap is remelted under controlled conditions there is no reason why the secondary metal produced should not compare favourably with certain grades of virgin metal.

The Cunard Line Centenary

IN these days when the Merchant Service is giving its full support to the national war effort, by carrying on so gallantly in the face of danger, it is appropriate that the centenary of the Cunard Line should be celebrated in this year of 1940. Samuel Cunard, an American, came to this country in 1838 with the object of securing the Admiralty contract for the transport of mails across the Atlantic and to establish a service of steamers sailing from Liverpool contract for the transport of mails across the Atlantic and to Halifax and on to Boston in the United States. Before that project could be carried through, however, he had to have the ships built, and in this he had the valuable help of Robert Napier, the eminent Scottish marine engineer, who not only provided the technical knowledge, but was responsible, through the generosity of his friends, for raising the necessary financial capital. Thus it was that the *Britannia* was built and made her momentous crossing in 1840, and so began the famous Cunard Line and the service that has given to the world such proud ships as the *Queen Mary* and the *Queen Elizabeth*.

BIRMINGHAM ALUMINIUM CASTINGS (1903) CO., LTD., has issued three pocket charts which have considerable practical value. No. 1 gives the mechanical and physical properties of a useful range of aluminium alloys and zinc alloys; it also gives the trade name of each alloy, the specification which it satisfies, the purpose for which it is most suitable, and some outstanding characteristics. No. 2 is concerned with the mechanical and physical properties and applications of aluminium and Elektron alloys on the same lines as No. 1, while No. 3 gives essential data on composition and heat-treatment of aluminium and Elektron alloys. They are issued in a very handy form and may be obtained from Birmid Works, Smethwick, Birmingham.

Production of Magnesium and Beryllium by Carbon Reduction

HIGH-TEMPERATURE reduction of magnesia with a carbonaceous agent in an electric furnace, the metal evolved being condensed in a very pure form, is by no means a new process. An unsatisfactory feature, however, has been the relatively slow rate of evolution of the metallic vapour. To overcome this, it has been proposed[1] to exploit the accelerating action of a heat-resistant oxide, such as silica. In one illustration of the procedure, 300 parts finely powdered magnesia, 127 parts powdered graphite, and 47 parts silica were briquetted with a tar binder and placed in a furnace at 1,500° C. and a pressure of 10 mm. mercury. Distillation of reduced magnesium was completed in 2 hours. An identical batch, except for the absence of silica, was run for the same period when the conversion to metal was found to be only 75% of that obtained with the first batch. This accelerating effect was also found to be exerted by chromium trioxide and calcium fluoride. A reduction mix comprising 300 parts magnesia, 127 parts graphite, and 9 parts calcium fluoride gave a magnesium yield equivalent to 50·2% of theory, as against only 32·2% with graphite alone. The yield of distilled magnesium was 73·7% of theory with a mix containing 300 magnesia, 127 graphite, 17 calcium fluoride, and 400 calcium oxide. The same quantities of magnesia and graphite in admixture with 31 parts chromium trioxide (Cr_2O_3) and 51 parts silica resulted in a 56·2% yield of distilled metal.

The problem of economic reduction of beryllium oxide with carbon has been solved along rather different lines. Normal high-purity beryllium oxide, it was revealed, suffers from the defect of sintering before the optimum reduction temperature in the electric furnace is reached. As a result, the surface exposed to the reducing action is considerably reduced, and the process is further slowed down owing to retention of beryllium vapour in the compact mass. The difficulties were overcome[2] by starting from an exceptionally high grade of oxide, in fact one containing less than 0·1% of total impurities (less than 0·02% each of silica, ferric oxide, calcium oxide and alumina). Such an oxide was far and away superior to the ordinary 99·7% material. In an induction furnace at a temperature of about 2,100° C. the high-grade beryllium oxide released its metal at the rate of 24·5% per hour, as compared with only 12·5% in the case of the 99·7% oxide. In both cases a stream of hydrogen was used to sweep the metallic vapour out of the reaction zone. Subsequently the vapour was rapidly cooled to avoid reoxidation by the carbon monoxide formed in the reaction. Exhaustive analyses are not essential in the selection of raw material. The essential requirement is that the mix should not sinter before reaching the reduction temperature, but should retain its original loose texture. Thus a sample which sinters at, say, 1,600° C. is obviously unsuitable. Another reliable criterion is the exceptionally high apparent density of beryllium oxides analysing at 99·9% or higher.

1 U.S.P. 2,205,658. Dow Chemical Company.
2 U.S.P. 2,204,221. Brush Beryllium Company.

Mr. Charles Russell Lang, C.B.E.

WE have to announce with sincere regret the death, on December 3, 1940, of Mr. Charles Russell Lang, C.B.E., Senior Director of G. and J. Weir, Ltd., Cathcart, Glasgow. Mr. Lang joined the firm in 1887 as works' manager, subsequently becoming a director and joint managing director.

In his association with G. and J. Weir, Ltd., Mr. Lang had, for many strenuous and active years, taken a leading and responsible part in carrying out successful developments in the firm's products, organisation and departmental arrangements. Few men worked harder during the stressful years of the 1914-1918 war, and his unceasing efforts at that time were recognised by the award of a C.B.E. in 1918.

Some Developments in Alloy Steel Production

By J. H. G. Monypenny, F.Inst.P.

The factors which have contributed to the development of the alloy steel industry are discussed, and a comparison made between old and new specifications showing the extent of progress in meeting more exacting demands on alloy steel. Attention is directed to the striking developments in the commercial use of stainless and heat-resisting steels resulting from improvements in detail, and the suggestion is made that more effective use of low ferro-chrome would result from a wider application of the lower chromium, higher nickel steel.

THE demand for the temporarily unattainable is a characteristic of human nature which never seems to change. A cynic would probably point to present conditions in Europe as an example of what may happen if to this characteristic is added brutality and unbridled licence, and argue therefrom that the human race would be better if the desire for something out of reach could be eradicated or at least kept under close control. But not all the effects of this human desire are evil; thus it is highly probable that much of the progress in alloy steel metallurgy has originated in a desire to obtain properties which seemed at the moment to be just beyond reach. Sometimes the goal to be attained concerned mechanical properties—e.g., higher tensile strength or toughness,—sometimes other properties, such as corrosion resistance, strength at high temperatures, magnetic properties; at other times it was the production of equal properties at less cost. All these factors have contributed in bringing the alloy steel industry in this country to its present state of development.

Perhaps the "high spot" at the present time regarding alloy steels concerns their use in aircraft, where the demand is frequently for higher tensile strength combined with adequate toughness, in order that weight may be cut down to a minimum. In addition, relative freedom from non-metallic inclusions is expected, not only because such inclusions may be regarded as microscopic flaws and therefore liable, possibly, to reduce the actual strength of the steel or to cause local concentrations of stress, either of which would tend to diminish the effective strength of some particular part, but also because their presence may impair the surface polish necessary in some engine detail to ensure smooth running. The standard attained in the steel industry in all these matters is extremely high. As regards combinations of strength and toughness, it may be interesting to recall the position during the early years of the last war. The manufacture of aircraft was then developing rapidly with a consequent demand for alloy steels of high tensile strength. A comparison of the properties available then and now will afford some idea of the extent to which ferrous metallurgy has meanwhile progressed.

Air Board Specifications

A survey of Air Board specifications issued during 1917, when we had been at war for over two years, shows that a tensile strength of 55–65 tons per sq. in. was regarded as characterising a "high-tensile" steel, and the specifications covering the supply of such steel (S 2, S 11, S 12, S 30) called also for a minimum impact value of 40 ft.-lbs. To obtain a value well over this minimum figure along with a tensile strength near the upper end of the specified range represented a real achievement. That this was the case is obvious from the crankshaft specification K 1 (April, 1917) and the more general specifications, S 33 and S 34 for bars, billets and forgings (issued June, 1918), which called for the somewhat higher tensile strength of 60–70 tons per sq. in. together with a minimum Izod value of 35 ft.-lbs. at 60 tons, falling to 30 ft.-lbs. at 70 tons. This graduated value indicates the difficulties experienced in obtaining high impact values with tensile strength over 60 tons per sq. in. Present specifications S 65 and S 81 call for 65–70 and 65–75 tons per sq. in. respectively, together with minimum impact values of 35 ft.-lbs., and a survey of a large number of current tests indicates that values of 50–60 ft.-lb. are regularly obtained with 70 tons per sq. in. tensile strength. Judged from this angle, S 11 requirements (which are still substantially the same as in 1917) appear relatively simple; in point of fact, it is not uncommon for Izod values of 90 or 100 ft.-lb. to be obtained in bars 1 in.–2 in. diameter, with a tensile strength of 60 tons per sq. in., figures which would have been regarded as quite impossible of attainment during the last war.

Actually, it is unnecessary to use such a highly alloyed steel as is specified in S 11 to meet the physical requirements of this specification in sizes up to 2½ in. or so. For example, within this range of sizes, steel containing about 1·5% manganese and 0·5% molybdenum will fully meet the specified requirements, a fact which has been evident for some time by the use of steels of this type for B.S.I. specification 28 2, which calls for the same physical tests as S 11, but does not specify the type of alloy steel to be used. Similarly, the requirements of other specifications—e.g., S 65, S 81—can be satisfactorily obtained within certain limits of size from steels of lower alloy content than are actually called for in these specifications. The use of these lower alloyed steels results not only in a saving in cost, but, more important still, a conservation of essential ferro alloys.

Similar improvements in toughness values are noticeable in "100-ton" steels of the air-hardening nickel-chrome type. Specification S 18 (March, 1917) called for 100 tons per sq. in. tensile strength and 8 ft.-lb. minimum impact value. S 28 (January, 1918) allowed a range of tensile strength of 90–110 tons per sq. in. with graduated values for elongation, reduction of area and impact; the last-named being 12 ft.-lb. minimum with 100 tons per sq. in. tensile strength. The modern equivalent of this specification returns to the 100 tons minimum, and also requires not less than 15 ft.-lb. Izod value. Actually, values of over 30 ft.-lb. are quite common, a recent test result being 108 tons per sq. in. tensile strength, 15% elongation, 48·5% reduction of area, and 42 ft.-lb. Izod value. Here again, if oil-hardening be permitted instead of air-hardening, the required properties may be obtained within certain limits of size by the use of steels of a lower alloy content than is specified.

One of the difficulties during the last war—i.e., the production of tensile strengths between 70 and 90 tons per sq. in. with reasonable toughness—arose on account of temper brittleness in nickel chrome steels. Steel works metallurgists who, like the author, were concerned with alloy steel development in that period, will remember early troubles in attempting to meet the requirements of specification 120 A—for connecting rod forgings,—which, *inter alia*, called for 70–80 tons per sq. in. tensile strength, 15% elongation, and 24 ft.-lb. impact value. In bars 1½ in. or so in diameter the problem could be solved by the use of steels which did not suffer from temper brittleness so markedly as nickel-chrome steels; thus the specified tests were obtained quite well from steel containing about 1¼% chromium plus a small amount of vanadium. Such a steel, however, will not harden completely when oil-quenched in bars or forgings 4 in. or so in diameter, and, unfortunately,

this fact not being realised in certain official quarters, the steel was used for master connecting-rod forgings; as might be expected, the tensile strength at the "big end," where the forging was 4 in. or 5 in. thick, nowhere approached the specified figure. As is now well known, temper brittleness may be removed entirely from nickel-chrome steels—which will, of course, harden satisfactorily in these larger sizes—by a suitable addition of molybdenum, which also, by retarding the tempering of the steel above about 500° C., allows the use of somewhat higher tempering temperatures to obtain a given tensile strength. The latter feature is also produced to a marked extent by small additions of vanadium; for example, Burton and Russell* showed that small additions of this metal to various steels resulted in a very slow fall in tensile strength and hardness as the tempering temperature of the hardened steels rose above 500° C. up to about 650° C. The effect is due apparently to a form of precipitation hardening as a result of the slow separation and agglomeration of vanadium carbide and even leads, in some cases, to a hump at about 600° on the curve when hardness is plotted against temperature. Effective use of the known actions of these two metals has enabled steels to be produced having tensile strengths of 80–90 tons, together with impact values which have an ample margin over the specified minimum of 25 ft.-lb.; moreover, these results can be obtained by tempering at temperature round about 600° C., a desirable feature, for example, where freedom from warpage during subsequent machining—possibly of a complex nature—is important.

High-tensile case-hardening steels show similar marked improvement. S 16 (issued March, 1917) called originally for a nickel-chrome steel to give 60–80 tons per sq. in. tensile strength with a minimum impact value of 30 ft.-lb., but difficulties in the higher range of tensile strength soon led to a sliding scale for impact value; in June, 1917, the specified figure ranged from 30 to 15 ft.-lb., the stipulated minimum falling as the tensile strength rose from 60–80 tons per sq. in. In August, 1917, there were further modifications, the range of tensile strength being lowered to 50–70 tons per sq. in., with which was coupled Izod values of 30–25 ft.-lb., the minimum value being related to tensile strength, such that the latter plus four times the Izod value was not less than 170. S 16 was discarded some years ago; its modern equivalent, S 82, requires a minimum of 85 tons per sq. in. tensile strength, with 25 ft.-lb. impact, and current practice indicates that the latter figure is well exceeded even when tensile strength is as high as 90 tons per sq. in.

One may similarly contrast the early difficulties with 5% nickel case-hardening steels with present regular practice. Specification S 17 (March, 1917) called originally for minimum values of 65 tons per sq. in. and 30 ft. lb., but this was quickly modified to 65–85 tons per sq. in., with a minimum Izod value on a sliding scale such that tensile strength plus twice Izod value was not less than 125. Later the range of tensile strength was lowered to 60–85 tons per sq. in., and the sliding scale modified so that tensile strength plus twice Izod value was not to be less than 115—i.e., a minimum value of 25 ft.-lb., with a tensile strength of 65 tons per sq. in. S 17, like S 16, fell into desuetude, but the modern version, S 90, calls again for minimum values of 65 tons per sq. in. and 30 ft.-lb.; current practice shows that the latter figure now causes no trouble, values of 40 ft.-lb. or so being regularly obtained with a tensile strength of 80 tons per sq. in.

Nitrided surfaces are of particular value in lessening wear. In some instances, however, the extreme hardness obtained from "Nitralloy," the chromium-aluminium-molybdenum steel originally developed for nitriding, may not be necessary or even desirable. The last few years have seen the increasing use of chromium-molybdenum steels of suitable composition, which, when nitrided, have surface hardnesses of 700–1,000 or thereabouts on the Vickers' diamond-hardness scale, and moreover possess high strength and toughness in the unnitrided parts. These steels find effective use in engine details, where resistance to wear is of considerable importance. Incidentally, some of them are of value as high-tensile steels for parts which do not require nitriding.

* "Precipitation Hardening in Three Steels Containing Vanadium," *J.I.S.I.*, 1938, II, p. 57.

Clean Steel

Mention has been made of the production of steels containing a minimum amount of non-metallic inclusions. Whilst this applies more particularly to steels melted in the basic electric-arc furnace, it is also a fact that acid open-hearth steels are being made of a surprising degree of cleanness. Such steels, indeed, serve many useful purposes in aero-engine construction as well as being of first-class importance in the production of forgings, both large and small, from which good transverse tests are required. In spite of the prominence which the subject of freedom from non-metallic inclusions has attained in the minds of metallurgists and engineers, a satisfactory method of obtaining a number representing the content of microscopically visible inclusions in a given steel, which is sufficiently accurate and reproducible by different observers to justify use for specification purposes as an acceptance test, has not yet been evolved. Methods of inclusion counts have been proposed which allot arbitrary numbers to certain groupings and types of inclusions as they appear through a microscope at some standard magnification; observations at different parts of a micro-section, cut in a definite way from a bar of standard size, are then summarised by strictly defined systems of counting. The results so obtained have been of considerable value in enabling steelworks' metallurgists to control and improve the products of their own works. No method yet proposed has won universal approval, however, nor is it certain that any of them is sufficiently exact, as mentioned above, to be used for specification purposes. This, however, is not altogether surprising in view of the obvious difficulties of assessing the relative effects of different types of inclusions, having different shapes and sizes and occurring in a more or less irregular distribution at different positions in sections taken from edge to centre from bars of standard size, but which may have been rolled from ingots of quite widely varying size. However, although one hears less nowadays about specified maximum "inclusion counts" than a year or two ago, the production of clean steel has not suffered thereby, nor is there generally serious disagreement between metallurgists in steel works and those in the engineering industry as to whether individual casts should be graded as clean or otherwise.

Stainless and Heat-Resisting Steels

The past year or two has seen no striking developments in the commercial use of stainless and heat-resisting steels, though improvements in detail have occurred in some, at least, of the types of these steels which are in general use. Perhaps the chief modification in composition and structure which has attained some degree of prominence is in connection with the production of steel with better machining properties, judged from the point of view of rapid production of parts in automatic or semi-automatic machines. Such improved machinability has been obtained either by increasing sulphur content, as in the production of ordinary free machining carbon steels, or by adding an equivalent amount of selenium. If increased sulphur content is the method employed, suitable amounts of molybdenum or zirconium are often added as well in order to produce the corresponding sulphides.

Whichever method is employed, the result is the formation of a large number of non-metallic inclusions in the steel, and it should be remembered that, whatever advantages may thereby accrue in machinability, the presence of these inclusions cannot be an unmixed blessing, otherwise the drive for "clean steel" for aircraft and other purposes would obviously lose its point. In the case of corrosion-resisting steels, an added complication may arise in regard to their response to corrosive attack, because the latter is

governed very largely by the continuity and permanence of the passive film which normally covers their surface. It seems probable that the presence of large numbers of non-metallic inclusions, be they sulphides or selenides, will provide so many more weak spots in this passive film, and hence make the steel more liable to attack by pitting. In certain applications, this possibility may be remote, and the use of these freecutting steels justified from the point of view of reducing the time and cost of machining operations. Thus, it is a fact that the production in large numbers of certain essential details of our war machine has been materially facilitated by the use of these freecutting stainless steels, with no detrimental effects on efficiency,—but in other cases, the potential reduction of corrosion resistance due to the inclusions may be a heavy price to pay for ease of machining. It is at least a matter which should be carefully considered by those to whom the improved machinability is an attraction.

As regards steels possessing resistance to scaling at high temperatures, the high-chromium steels, whether of the "martensitic" or "ferritic" types, continue to serve many useful purposes. Where greater strength at a red heat than these steels possess is necessary, the austenitic chromium-nickel steels, with or without additions of other metals, such as silicon or tungsten, are generally selected. Their actual composition varies, of course, with the conditions of use which they have to meet, and while some of them are wholly austenitic others possess a markedly duplex structure of austenite and ferrite as a result of a high content of chromium, silicon, tungsten, aluminium or other metals which tend to restrict the gamma field, and a relatively low-nickel content. Some of these duplex steels become brittle on heating for longer or shorter periods at moderate temperatures—e.g., 500° to 800° C.—the cause being very probably transformation at these temperatures of some or all of the ferrite to the sigma phase. The structure of this peculiar phase, which is hard, very brittle, and non-magnetic, is still unknown, and full information regarding the ranges of composition in which it may form is also lacking, but enough data are available to indicate approximately certain ranges of composition, in which pronounced embrittlement may take place under temperature conditions which frequently occur in service.* The most important feature would appear to be that the sigma phase is formed from ferrite and not from austenite, hence it may reasonably be expected that steels which are fully austenitic will not suffer from sigma formation. On the other hand, one should look with some suspicion on heat-resisting steels, which are mainly austenitic in character, but contain also an appreciable amount of ferrite in their structure—due, for example, to a chromium content well over 18 or 20%, or to the addition of one or more strong ferrite-forming elements to an austenitic steel having approximately this chromium content, in both cases without a corresponding increase in nickel, until it is shown that such steels do not seriously embrittle when held at a dull red heat.

The very large consumption of stainless and heat-resisting steels for war purposes has made heavy demands on the supply of the alloys used in their manufacture, particularly low-carbon ferro-chrome, and hence it is desirable that the latter alloy should not be used in needlessly large amounts—i.e., that the chromium content of the steels should not be higher than is really necessary for the purposes for which they are required. Probably this is generally the case, but the possibility of more economical use seems evident in some of the purposes for which the austenitic chromium-nickel steels are frequently selected. Custom over a period or some years has generally called for a composition of about 18% chromium and 8% nickel in these austenitic steels. There is, of course, a relationship between the amounts of these two alloys which must be added to the steel in order to obtain a stable austenitic structure which will not work-harden at too high a rate, and hence, within somewhat narrow limits, nickel may replace chromium and vice versa. Actually, ease of working is facilitated by lowering chromium to 15% or so and increasing nickel a corresponding amount; and no appreciable difference in resistance to many corrosive media can be found between steel of such composition and the customary "18/8" type. During the past few years any incentive to produce such modifications in composition has been checked by the high cost of nickel, but, under present conditions, this is less important than effective use of available raw materials. There are many purposes including some of war-time importance, for which a chromium content of 14 to 16%, combined with some 10 or 11% of nickel provides ample corrosion resistance, and, incidentally, greater ease in working than the customary "18/8" steel. The use of the latter in the past has frequently been dictated mainly by the fact that it was a more or less standard steel, readily available, and not because it was necessarily the best composition for all purposes. The writer would suggest that a more effective use of low-carbon ferro-chrome would result from a wider application of the lower chromium higher nickel steel.

* For a summary of these data see METALLURGIA, March, 1940, p. 143, and July, 1940, p. 87.

Making High Grade Steels

THE term quality is frequently applied to steels irrespective of their grade. It is, however, essentially a relative term, and should only be applied when the steel is to be used for purposes for which it is intended. It is well known that specifications vary considerably, each being designed to meet a certain specified field, and even what might be termed the commoner grades of steel may be termed quality steels, providing they satisfy requirements in their particular sphere. The trend in modern manufacture is towards improved quality in each grade, particularly is this true of those steels upon which much forging work is necessary, and which are required to pass very stringent tests. Such steels are invariably expected to satisfy these tests after forging and heat-treatment, and as the operations involve much costly work it is important that the quality of the steels is of a high order. It is for this reason that high-grade steels are produced which have superior mechanical properties and are capable of giving greater reliability and increased service.

It is recognised that improved quality is one of the primary factors in satisfying the needs of modern engineering, and there is an increasing demand for high-grade steels as distinct from the normal mass-produced steels. Although quality is of first importance, it will be appreciated that economy in production has some significance. Thus, design of furnace, the process and its control must be carefully considered in the light of experience and research in order to facilitate the production of these high-grade steels economically. Whatever process is adopted, whether by open-hearth, electric or crucible, scientific control of the various operations is now considered to be essential to success, but even with advanced methods of control steel manufacture is not entirely a science, and it is questionable whether the skill of the steelmaker will ever be rendered unnecessary. It is for this reason that accumulated experience, as well as research data, is so valuable in the manufacture of high-grade steels. Thus, such operations as making and melting the charge, finishing the bath, tapping the heat, and teeming from the ladle, are of vital importance, whilst the solidification of the metal in the moulds also has an important influence on the quality of the steel produced.

The particular process adopted is largely governed by the type of steel manufactured and the size of ingots required, and for a wide range of high-grade steels the acid open-hearth process is the most efficient. The superiority of acid steel is largely due to its greater ductility and resistance to shock, important characteristics which are partly due to the care exercised in the selection of the charge, but more particularly to the nature and influence of the slag which gives a greater purity and freedom from oxides.

Metallurgical Progress in the Foundry in 1940

By J. G. Pearce, M.Sc., M.I.Mech.E., F.Inst.P.

In the main, iron foundries have been working under high pressure during the year, largely to meet war needs, and there has been considerable interruption of normal research and development work. In this brief review attention is directed to some work of the British Cast Iron Research Association.

WAR needs have caused considerable interruption to the normal progress of research and development in the foundry industry, as in other spheres. The procedure of works' research organisations and laboratories and research institutions has been modified considerably, and of this it is at present possible to say very little. The following relates in particular to the work of the British Cast Iron Research Association, but limitations of time and space prevent more reference to developments elsewhere.

Anti-Glare

Before the end of 1939 the B.C.I.R.A. was officially approached to constitute an Anti-Glare Committee on which the Ministry of Home Security would be represented, for the purpose of assisting both the industry on the one hand and the authorities on the other to meet the requirements of the Civil Defence Act. This calls on foundries working in blackout periods to avoid glare and offers a grant of 50% of the cost of approved schemes, the approval being entrusted to the B.C.I.R.A. Anti-Glare Committee, of which the writer is chairman. During the first year of the war something like 1,500 inquiries were received. A report on "A.R.P. for Cupola Furnaces" was circulated to members of the B.C.I.R.A. before the middle of 1939, and in October of that year it was enlarged and issued as Special Publication No. 4, some 2,000 copies of which were circulated. At that time no knowledge or experience of the problem had been gained, and a second report, Special Publication No. 6, "Anti-Glare Equipment for Cupolas," was widely circulated in May, 1940, to the industry, to Government departments, and local authorities. Foundries now have a choice of some half dozen types of equipment for screening the top of a cupola furnace. In this work, as in other problems in which the cupola is concerned, it has been found necessary to consider each furnace and each scheme on its merits, and no cut-and-dried solution is practicable. At the same time, it is now possible to design new furnaces so that they can be fitted with anti-glare devices offering a reasonable prospect of permanence and satisfactory working.

High-duty Cast Iron

So far as other work is concerned, considerable attention has been given to the extended use of high-duty and other cast irons to relieve pressure on the capacity of the steel and non-ferrous industries. The present writer drew attention to the general problem in a paper to the June Conference of the Institute of British Foundrymen.[1] The field of extended uses was grouped into four sections—war and defence, the building industry, including castings used on, in and about buildings and civil engineering work generally, the engineering industry, and industries other than engineering consuming castings.

Two Special Publications issued by the B.C.I.R.A., in addition to those mentioned above, are the following:—"Recommended Methods for the Hardness Testing of Chilled Rolls." For some years difficulty had existed through a German design of rebound hardness tester giving higher hardness figures than the scleroscope, frequently used in this country and in U.S.A., and itself capable of considerable improvement. Another report, following on several years of work by the B.C.I.R.A. Pig Iron Sub-Committee, and issued just before the war, was an elaborate pig-iron grading scheme for hot-blast, cold-blast, hæmatite, and basic pig irons, and both white and grey refined pig irons.

Vitreous Enamelling

A section of the industry making enormous progress immediately before the war was that devoted to vitreous enamelling and technical developments in this field are supervised by the Joint Committee on Vitreous Enamelling of the B.C.I.R.A. and the Institution of Vitreous Enamellers. This Joint Committee issued an elaborate bibliography on vitreous enamelling, and a glossary of terms used in the industry. In addition, following experimental work, a "Recommended Method for Testing the Acid Resistance of Vitreous Enamel"[2] was evolved, and this has recently been extended to cover tests on production work in the enamelling shop.

The machinability of cast iron is a property very much to the fore at the present time, and A. A. Timmins has shown[3] that annealing to decompose pearlite, such as is found in cast iron in the as-cast state, to the more easily machined ferrite, is easily accomplished at temperatures below the critical point, and the nearer the annealing temperature is to the critical point, the quicker is the annealing accomplished. If temperatures above the critical point are used, a slow rate of cooling after annealing is essential.

Cast Crankshafts

One of the most striking developments in recent years, now making considerable progress, is that of the cast crankshaft, and A. J. N. Smith[4] has given an account of the production methods and types of material used. This development, primarily undertaken for the automobile engine, is now spreading to the oil engine. The extent and importance of applications of cast iron in modern automobile construction has been dealt with in a very interesting paper by E. C. Toghill and R. V. Dowle,[5] and it is clear that modern cast irons are used in these applications, not because the material is cheap, but because its particular properties make them uniquely suitable for the purposes for which they are used. R. C. Shepherd[6] has also given an account of castings used in oil-engine production.

The problem of non-metallic inclusions in cast iron is not only important on account of the effect these inclusions have on properties, but has a great theoretical interest in view of the possible connection between these inclusions and the formation of graphite. Much work has been done recently, notably by E. Taylor Austin, on the chemical methods of determining inclusions. A lengthy report is about to be issued by the Iron and Steel Institute by H. Morrogh, dealing exhaustively with inclusions as seen under the microscope, and with their description and identification. The divergence between the results of the two methods of approach offers one of the most interesting problems of the immediate future for solution.

1. Pearce, J. G. "Extended Uses of Cast Iron, with Special Reference to War Conditions." (Institute of British Foundrymen.) *Foundry Trade Journal*, 1940, vol. 62, June 13, pp. 437–438.

2. Joint Committee on Vitreous Enamelling. "Recommended Method of Testing the Acid Resistance of Vitreous Enamel." *Foundry Trade Journal*, 1939, vol. 61, December 7, pp. 395–397.

3. Timmins, A. A. "Decomposition of Pearlite in Grey Cast Iron. (Iron and Steel Institute, May, 1940.) *Foundry Trade Journal*, 1940, vol. 63, August 15, pp. 109–110, and August 22, pp. 121–123.

4. Smith, A. J. N. "Cast Camshafts and Crankshafts." Coventry Engineering Society *Journal*, 1939, vol. 20, November-December, pp. 265–274.

5. Toghill, E. C. and Dowle, R. V. "Applications of Cast Iron in Modern Automobile Construction." (Institution of Automobile Engineers, March, 1940.) *See also Foundry Trade Journal*, 1940, vol. 62, May 23, pp. 383–384, and May 30, pp. 405–404, 406.

6. Shepherd, R. C. "Production of Oil Engine Castings." *Journal of the Institution of Production Engineers*, 1939, vol. 18, November, pp. 445–469.

The Metallography of Inclusions in Cast Irons and Pig Irons

The metallography of small particles in the microstructure of cast iron has been studied and a preliminary scheme of their classification developed. Throughout, these particles are referred to as "inclusions," but it is suggested that they should be termed "minor phases." Using this classification, the various inclusions are considered and results are given of experiments carried out to elucidate the nature and mode of occurrence of these particles.

MANY and varied are the opinions expressed regarding inclusions, but they are generally considered as something inferior in relation to the metal. Inclusions are present in all commercial metals to some extent, although often in very small quantities. There has been considerable discussion on the effect of inclusions in cast iron, and theories have been put forward implying that these inclusions exert effects on the structural characteristics of this alloy. The terms "non-metallic inclusion" and "slag inclusion" are more specific in themselves, but throughout the literature both have been used very loosely. The word inclusion is used in a paper* by Mr. H. Morrogh, of the British Cast Iron Research Association, not because it is a good one, but rather for lack of a better one, and because it is the commonly accepted word for these minor structural constituents.

A large number of isolated researches have been carried out which are concerned directly and indirectly with inclusions in steels and cast irons; these are considered and correlated, wherever possible, with results obtained by the routine microscopic examination of cast irons over a number of years. Of considerable interest is a preliminary scheme of classification for inclusions in cast irons and pig irons, which the author has developed. Using these classifications the various inclusions are considered under appropriate headings. Results are incorporated of various experiments which have been carried out to elucidate the nature and mode of occurrence of these particles.

Preliminary Scheme of Classification

From the points of view of their colour, morphology and chemical constitution, the inherent inclusions in cast irons and pig irons may be classified arbitrarily into a few groups. Such a classification is given below; this was actually drawn up before any experimental work had been done, which subsequently indicated that inclusions in different groups in the present classification might be grouped together solely according to chemical constitution. However, it has been used because it provided the basis on which the constitution and mode of formation of the inclusions were investigated. It is realised that the classification does not, in itself, solve the ultimate identity of the inclusions concerned.

Group I.—Manganese sulphide, iron sulphide and composite inclusions of these two.

Group II.—Pink Inclusions:

(*a*) Red-pink and idiomorphic.
(*b*) Blue-pink and allotriomorphic.
(*c*) Blue-pink and idiomorphic.

Group III.—White or faint grey inclusions:

(*a*) Idiomorphic.
(*b*) Allotriomorphic.

Group IV.—Inclusions produced by alloying with zirconium.

Group V.—Inclusions produced by alloying with aluminium.

Group I.—Manganese Sulphide, Iron Sulphide and Composite Inclusions of these Two.

It is convenient to deal, in this section, with both iron sulphide and manganese sulphide. These inclusions are very well known, and it is generally recognised that the dove-grey idiomorphic inclusions in cast irons are manganese sulphide, and that the khaki-coloured inclusions, present in irons having low manganese contents, are iron sulphide. In commercial materials the effects of manganese and sulphur are intimately connected. Information regarding these inclusions is to be found in three lines of investigation:—

(*a*) Descriptive metallography of the mode of occurrence of the inclusions;

(*b*) Study of systems relevant to these inclusions, for instance, the systems Fe–S, FeS–MnS, Fe–FeS–MnS–Mn, Fe–S–C, Fe–S–P, etc.;

(*c*) Consideration of the facts known about the desulphurising action of manganese.

Much purely metallographic work has been done on manganese and iron sulphide inclusions, equilibrium diagrams pertaining to systems connected with them have been extensively investigated, and many investigations have been performed and much theory has been propounded on the desulphurising action of manganese.

In irons which are completely free from manganese, the sulphur is in the form of iron sulphide (FeS). Additions of manganese to such irons result in the disappearance of iron sulphide, owing to the formation of manganese sulphide. The reaction may be represented by the following equation:—

$$FeS + Mn = MnS + Fe.$$

In order to neutralise all the sulphur as manganese sulphide, it is necessary to have an excess of manganese over the theoretical percentage indicated by the formula (MnS). This fact is due to the reversibility of the reaction, as was originally suggested by Baykoff, and confirmed experimentally by Herty and True:—

$$FeS + Mn \rightleftharpoons MnS + Fe.$$

In irons (or steels) containing insufficient manganese to neutralise the sulphur entirely as manganese sulphide, the dove-grey manganese sulphide occurs associated with the khaki iron sulphide in the form of duplex inclusions.

From a review of the literature on the mode of occurrence of manganese sulphide and on the desulphurisation of iron by manganese, which is given in the paper, the following facts emerge: Manganese sulphide is only slightly soluble in molten cast iron, the solubility increasing with increasing temperature. At any given temperature, any excess manganese sulphide will tend to rise and segregate at the surface of the molten metal. On cooling from such a specified temperature, the dissolved manganese sulphide will be deposited in a dendritic form. These points are entirely confirmed by the observed morphology of manganese sulphide in cast irons.

In cast irons poured at fairly low temperatures ($< 1{,}350^\circ$ C.), manganese sulphide occurs in typical compact idiomorphic crystals, whereas in irons poured at high temperatures ($> 1{,}400^\circ$ C.) the manganese sulphide tends to occur in recognisable dendritic forms in the case of high-sulphur irons and as "anchor-shaped" crystals in low-sulphur irons.

The effect of pouring temperature on the morphology of manganese sulphide is discussed, and it is stated that the

*Iron and Steel Institute, 1941, Annual General Meeting. Advance copy.

fact that manganese sulphide exhibits the same morphological changes with decreasing pouring temperature as do the primary metallic dendrites, supports the view that manganese sulphide is soluble in molten cast iron, from which it is deposited in the solid form as cooling proceeds.

A study of malleable iron samples has revealed that at least two different forms of temper carbon nodules can exist. Generally speaking, the temper carbon appearing in whiteheart malleable iron is in a compact spherulitic form. In blackheart malleable irons the temper carbon generally exists as an aggregation of small graphite plates. The real cause of the two different types of temper carbon nodule is the fact that, in general, whiteheart malleable irons contain iron sulphide, and blackheart malleable irons contain only manganese sulphide.

Group II.—Pink Inclusions.

This group comprises the inclusions usually referred to in the literature as titanium cyano-nitrides. These occur in nearly all cast irons in the form of small cubes. They are considerably harder than the metallic matrix, and tend, usually, to stand up in appreciable relief. Whether viewed under dry or immersion objectives, they present brilliant surfaces. With regard to the occurrence of this constituent, it can be said that in cast irons it shows a marked tendency to occur associated with manganese sulphide in the extra-dendritic regions of the structure. This may be due to the fact that it forms from the melt in a similar manner to manganese sulphide. The colour of titanium cyano-nitrides in cast iron vary in colour from deep salmon-pink to very faint pink. It is significant to note that the faint-pink cyano-nitrides usually occur with relatively high titanium contents and consequently with relatively large amounts of titanium carbide.

A blue-pink inclusion has been observed in various cast irons containing titanium and insufficient manganese to neutralise all the sulphur as manganese sulphide. This constituent has been prepared in a number of melts and shown to be probably titanium sulphide. Two forms of the titanium sulphide inclusion occur, one allotriomorphic and one idiomorphic. The complicated optical properties of this inclusion, as revealed by the metallurgical polarising microscope, are described in detail.

Group III.—White and Faint-grey Inclusions.

The inclusions belonging to these sub-groups appear in all titani-ferrous irons and in irons containing vanadium. Usually, titanium carbide occurs in the form of cubic crystals, but occasionally it occurs in an allotriomorphic form. The latter occurring more frequently in titani-ferrous irons containing very small amounts of vanadium. Both titanium carbide and vanadium carbide have cubic crystal structures, and in irons containing both titanium and vanadium these two carbides appear to crystallise isomorphously or to yield solid solutions.

The effects of test-bar diameter and titanium content on the number of titanium carbide and titanium cyano-nitride crystals have been determined by means of inclusion counts. An attempt was made to determine whether the solubility of titanium carbide in austenite could be detected by the inclusion count method.

Group IV.—Inclusions Produced by Alloying with Zirconium.

The effect of zirconium additions in amounts up to about 0·5% was studied. It was found that additions of 0·04% have no effect on the inclusions present in a titani-ferous cast iron. Additions of zirconium above 0·04% result in the appearance of a lamellar orange-yellow to grey inclusion which completely replaces the manganese sulphide at 0·09% zirconium. At 0·13% zirconium, small crystals, blue-grey in colour and cubic in outline, are formed. These are probably zirconium carbide. They gradually increase in number with increasing zirconium content. With 0·15% zirconium, the lamellar orange-yellow to grey inclusions become replaced by the polygonal form of the same phase until, at 0·25% zirconium, the lamellar form has completely disappeared. With 0·25% zirconium, the titanium carbide begins to be replaced by a slightly softer pinkish constituent which is probably a complex titanium-zirconium sulphide. At 0·29% zirconium all the titanium carbide in the series studied was replaced by this new phase.

Group V.—Inclusions Produced by Alloying with Aluminium.

Several sets of irons with aluminium contents ranging from 0 to 10% were examined. These irons all contained enough manganese to balance the sulphur contents. The actual manganese contents ranged from 0·45% to 0·75% and the sulphur contents were all below 0·05%. In all the series examined, the same changes in the inclusions occurred with increases in aluminium content. Up to about 2% of aluminium the only inclusions present in these series were normal idiomorphic manganese sulphide crystals. From 2% to 3·7% of aluminium the manganese sulphide crystals appeared to become much softer and were easily damaged during the polishing operation. Nevertheless, they still retained their characteristic idiomorphic outline. With aluminium contents above 4% the idiomorphic manganese sulphide was replaced by a phase of a similar colour, but which was always perfectly spherical in outline. From 4% to 10% of aluminium the spheroids became larger and softer, being at the same time proportionally more difficult to polish. These spheroidal inclusions were optically isotropic and exhibited translucency effects similar to those of manganese sulphide.

Conclusion

Throughout this paper the small particles in the microstructure of cast iron are referred to as "inclusions." There appears to be a fairly general agreement that the terms "inclusion," "slag inclusion," and "non-metallic inclusion" are not very satisfactory for the collective description of these particles. Nevertheless, this has not prevented a liberal use of the terms, and the literature of ferrous physical metallurgy demonstrates a chaos of ideas on the subject, brought about in the first place by the lack of enforcement of exacting definition. In quite a large number of references, the particles are dealt with as a separate group of constituents entirely different from the major phases of the metallic matrix, with the implication that they are insoluble in either the solid or the liquid metal. In some extreme cases "inclusions" have, by analogy, been endowed with a misleading biological significance.

The chemical determination of oxides and silicates in steels and cast irons has proceeded apace in the last few years, and quite frequently this branch of activity is referred to as the analysis of non-metallic inclusions, etc. Thus there are two points of view on the question which are now actively developing—the chemical and the metallographical. At this point the question arises: Are the chemist and the metallographist talking about the same thing? In the case of steel, these two lines of investigation are probably correlative, but in the case of ordinary cast irons this is not so at the moment. The only "inclusions" seen in ordinary cast irons are manganese sulphide, titanium carbide, titanium cyano-nitride and perhaps iron sulphide. So far, the metallographist has not been able to detect oxides or silicates of iron, manganese or aluminium in ordinary commercial materials. From the point of view of the microscope, they do not exist, are completely soluble in the metal, or exist in such a finely divided form that they are not resolved. It is seen that the chemist and the metallographist have been tempted to use the same group of words to describe what are very different constituents—different in chemical composition, in mode of distribution and in order of size.

Portevin and Castro have pointed out that the term "inclusion" connotes a substance essentially foreign to the constitution of the alloy, perhaps detrimental to it, and more or less insoluble in the metal. With regard to such constituents as mechanically trapped furnace slag and moulding sand, it is obvious that the term "inclusion"

[*Continued on page 46*

Development of Low-alloyed High-speed Steel

By D. W. Rudorff, A.A.I.E.E., F.R.S.A., M.Inst.F.

Research work on high-speed steels has been intensified during the past year or two, not only to improve their capacity for service, but with a view to modifying the compositions to enable the greater use of alloying elements more readily available. This article deals more particularly with some recent developments in Russia, in which high-chromium steel is alloyed with tungsten, molybdenum and vanadium.

FOR many years the main alloying constituent in high-speed steels has been tungsten and, in addition to carbon, manganese and silicon, chromium, vanadium, molybdenum, and cobalt are further constituents that may be present, usually, however, chromium is present with tungsten. None of the recognised compositions appears to be successful in combining all the desirable properties so as to create the ideal material for all applications of cutting. Research is continuously in progress in order to approach more nearly the ideal material, but difficulties encountered in obtaining adequate supplies of certain alloying elements has directed attention to the development of new high-speed steels, and much progress has been achieved and reference to work carried out in Russia will be of interest.

A recently published report* by Prof. H. A. Minkevitch and O. S. Ivanov, of the Moscow Steel Institute, is concerned with the development of new types of high-speed tool steels in Russia. Convinced that only through the alloying of high-chromium steel with tungsten, molybdenum and vanadium is it possible to obtain a tool steel possessing great red-hardness, these investigators focused their attention upon the development of a high-chromium steel with lower content of tungsten and molybdenum than is encountered in the usual types of high-tungsten and high-molybdenum tool steels.

The graph reproduced in Fig. 1 shows secondary hardness versus temperature of various steels studied by the investigators in the earlier stages of their work. According to Table I, these steels were of the high-chromium-high-carbon type alloyed with tungsten and vanadium, or molybdenum and vanadium. This tabulation also contains the composition of a standard high-tungsten steel.

TABLE I.

—	C, %	Cr, %	Mo, %	W, %	V, %
Steel 627...	0·97	10·2	—	3·71	1·0
„ 708...	0·81	8·67	—	2·5	0·78
„ 720...	0·81	7·32	—	2·62	0·99
„ 722...	0·92	9·0	1·7	—	1·0
„ FR I.	0·68–0·8	3·8–4·6	0·3	17·5–19·0	1·0–1·4

As was to be expected, the proposed new steels proved to be somewhat inferior in resistance against softening in comparison with that of the high-tungsten steel F.R.I. This stage of research, however, resulted in the development and subsequent industrial application of two high-chromium high-carbon steels. These steels, developed jointly by H. A. Minkevitch, V. S. Vladislov, and O. S. Ivanov, are designated E.I. 173 and E.I. 184. Their composition is given in Table IV. It must be mentioned that at an earlier date (in 1935) two high-carbon high-chromium steels containing 1·5–1·8% silicon, in addition to vanadium, had been proposed by S. A. Kosev, A. N. Hosan, and M. B. Reznik. The compositions of these two steels, designated E.I. 116 and E.I. 172, are likewise included in Table IV.

Regarding the actual production of the steels mentioned so far, it is interesting to note that according to authoritative estimate, the output in 1939 of low-alloy tool steels in Russia was made up as follows :—Steel E.I. 184 : 55%, E.I. 172 : 30%, E.I. 161 : 15%. The production of these steels, their physical characteristics with various heat-treatments, and their resistance to softening in various services, have been discussed at length in Russian metallurgical literature. Here it will be sufficient to requote a few data concerning the cutting properties of steels E.I. 172 and E.I. 184, as compared with the standard high-tungsten steels R.F. I. and R.

When plotting the $v = f(T)$ characteristics of these steels on a logarithmic base, these are represented by straight lines of various slopes, the slope being greatest in the case of steel E.I. 172, somewhat less steep for steel E.I. 184, and smallest for steels R. and R.F. I. This fact signifies, of course, that the increase in temperature of the cutting edge with augmented cutting speed, affects the tool life with steel E.I. 172 to a higher degree than that with steel E.I. 184, while the latter is in turn more affected than the tool life of steels R. or R.F. I. Or, in other words, the red hardness of steel E.I. 172 is smaller than that of steel

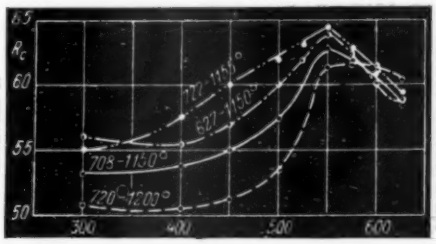
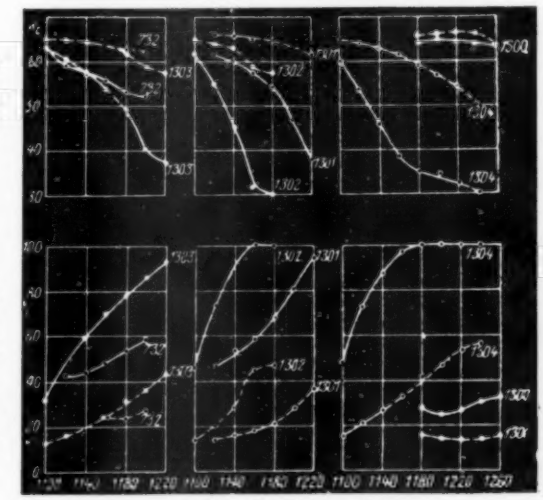


Fig. 1. Secondary hardness of high-chromium steels alloyed with small percentages of tungsten and vanadium or molybdenum and vanadium.

Fig. 2.—Influence of quenching temperature upon hardness and amount of residual austenite.



* Prof. Dr. H. A. Minkevitch and O. S. Ivanov. "New Low-alloyed High-speed Tool Steels." *Metallurg*, No. 1, 1940, pp. 31–46.

E.I. 184, while the red hardness of the latter is in turn inferior to that of steel R. or R.F. I.

Expressed in output per cutting edge, that of steel E.I. 184 is on the average 90%, and that of steel E.I. 172 is 85–80% of the output obtainable with the standard high-tungsten steels. But under very severe conditions these percentages are likely to decrease further. The tool life of the two mill cutters made with E.I. 184 and E.I. 172 respectively, as compared in Table II, establishes clearly the superiority of steel E.I. 184. Incidentally, the difference between the wearing qualities of the two mill cutters becomes still more pronounced as cutting conditions are increased in severity. This fact is particularly evidenced by the characteristics of drills made of these materials. In view of these facts, steels E.I. 184 and E.I. 172 could by no means be considered satisfactory substitutes for high-tungsten steel. It is also mentioned that the forging qualities of these two steels are rather poor.

At the end of 1937, the programme of the Moscow Steel Institute was enlarged, in so far as the problem of replacing vanadium and tungsten by titanium and molybdenum was included in the task of finding a substitute for high-tungsten steel. Increased emphasis was also laid on the demand that any such substitute steel must be simple to produce. In a first series of investigations the following six steels were tried out :—

varied from 1,150° to 950° C. The best forging qualities were found to obtain in the case of steel 1300. Steel 732 also forged well, but the other steels gave poor results. Immediately after forging, the 42 × 42 mm. bars obtained were subjected to heating at 800–750° C. for 2 hours. They were then cleaned and rolled into rods of 25 mm. diameter, which were cooled in pits. No defects due to rolling were observed. The phosphorus and sulphur distribution was found to be uniform throughout the material.

TABLE II.

WEAR ENDURANCE OF WORM GEAR CUTTERS.

Material cut : Chrome-nickel steel of 215 Brinell hardness.
Cutting speed : 30·4 m./min.
Depth of cut : 4–3 mm.
Cooling medium : Machine oil.
Wear endurance : With steel EI 184 : 1 hour 30 mins.
" " " " EI 172 : 0 " 56 "

The critical points were obtained with the Chevenard method. The test-piece was heated to 1,175° C. with a heating speed of 16° C. per min., followed by cooling in air of room temperature. It was found that point Ac_1 lay within a comparatively wide temperature range. The critical points of all six steels investigated are included in Table III. In all these steels, the transformation of austenite into eutectoid was found to occur in the range from 750° to 800° C.

TABLE III.

Steel No.	C.	Cr.	Mo.	W.	V.	Ti.	Si.	Mn.	Point Ac_1, °C.	Point Ar_1, °C.	After Heating to °C.
732	0·78	7·72	3·67	—	1·21	—	0·45	0·54	870/920	800/760	960
1300	0·89	4·49	3·76	—	2·21	—	0·38	0·13	840/880	800/750	910
1301	1·02	9·76	2·02	—	1·28	—	0·42	0·42	825/880	790/770	930
1302	1·0	9·77	3·7	—	0·3	1·0	0·36	0·22	835/900	780/750	930
1303	1·02	10·02	3·86	—	1·25	—	0·38	0·32	810/860	760/710	930
1304	1·08	9·72	—	4·21	0·22	0·92	0·42	0·28	800/860	780/740	930

As the investigators point out in their report, a comparative study of steels 732 and 1303 permits clarification of the influence of the height of the chromium content ; while a comparison of steels 1303 and 1301 sheds light upon the influence of the molybdenum percentage. Finally, a comparison of steels 1303 and 1302 is apt to show the effect of the substitution of vanadium by titanium, and this applies also to steel 1304, which can be used to establish the effect brought about by largely replacing vanadium by titanium in steel E.I. 184.

The steels were produced in a high-frequency laboratory furnace at the Electrostal Works. From each heat an ingot of about 50 kilogs. was cast. The forging temperatures

The influence of the hardening temperature upon the microstructure, upon the amount of residual austenite, and upon the hardness, were investigated on test-pieces measuring 10 × 10 × 30 mm. Heating was carried out in a barium chloride bath, the heating time being 5 mins. Quenching was done in mineral oil. Three samples were tested at each heating temperature. After hardening, one of these pieces was submerged in liquid air. The amount of residual austenite was obtained by the magnetic method. This is, however, somewhat inaccurate, and the results reported in Fig. 2 are therefore about 1–3% too low. The latter graph also includes a record of hardness versus tempering temperature. A comparison of the percentages

TABLE IV.

Steel.	% Constituents.							Transformation Range, °C.	Optimum Hardening Temp., °C.	Residual Austenite, %	Hardness after Quenching, Rc.	Tempering Temp. °C.	Number of Tempers.	Hardness after Tempering, Rc.
	C.	Cr.	Mo.	W.	V.	Si.	Mn.							
E.I. 172	1·1–1·5	11–13	—	—	2·1–2·5	1·5–1·8	< 0·4	940–1020	1,240	60	55	540	2	61
E.I. 184	0·8–1·0	7–9	—	3·5–5	1·1–1·5	0·5–0·8	< 0·4	870–950	1,200	60	55	550	3	62
1300 (E.I. 260)	0·9–1·0	5–6	3·5–4	—	2–2·5	< 0·4	< 0·4	810–880	1,240	35	62	550	1	63
1300 B (E.I. 260 B)	0·95–1·05	5–6	3–4	2–3	2–2·5	< 0·4	< 0·4	850–890	1,240	35	62	550	1	63
1300 X (E.I. 260 X)	0·95–1·05	7–8	3–4	—	2–2·5	< 0·4	< 0·4	870–950	1,240	45	58	550	3	63
E.I. 116	0·75–0·35	9·5–10·8	—	—	1–1·35	1·5–1·8	< 0·4	870–950	1,220	60	55	530	2	61
E.I. 173	0·9–1·0	9–10	—	2–2·5	1–1·2	0·6	< 0·4	850–900	1,200	65	54	550	3	62
E.I. 161	0·55–0·65	6·5–7·5	0·2–0·35	6·5–7·5	< 0·3	0·3–0·6	0·3–0·6	850–900	1,200	—	59	530	1	61
E.I. 243	1–1·2	10–13	3–4	—	2–2·5	0·9–1·6	< 0·4	—	1,250	—	51	550	1	—
E.I. 244	1–1·2	10–13	—	—	2–2·5*	0·9–1·6	< 0·4	—	1,250	—	51	550	1	62
Z.G. 1	1–1·2	4–4·5	2·5–3	—	3·0–3·5	< 0·4	< 0·4	—	—	—	—	—	—	—
Z.G. 3	1·2–1·4	4–4·5	3–3·5	—	3·5–4·2	< 0·4	< 0·4	—	—	—	—	—	—	—
R.	0·65–0·78	3·8–4·6	Up to 0·3	17–18·5	0·5–0·8	< 0·4	< 0·4	—	—	—	—	—	—	—
R.F. I.	0·68–0·8	3·8–4·6	Up to 0·3	17·5–19·0	1–1·4	< 0·4	< 0·4	—	—	—	—	—	—	—
O.R.F. II.	0·9–1·0	4·1–4·6	—	11–13	2–2·6	< 0·4	< 0·4	—	—	—	—	—	—	—
Mo-Max	0·75–0·85	4	8	2	7	< 0·4	< 0·4	—	—	—	—	—	—	—

* Plus 0·3–0·4% Ti.

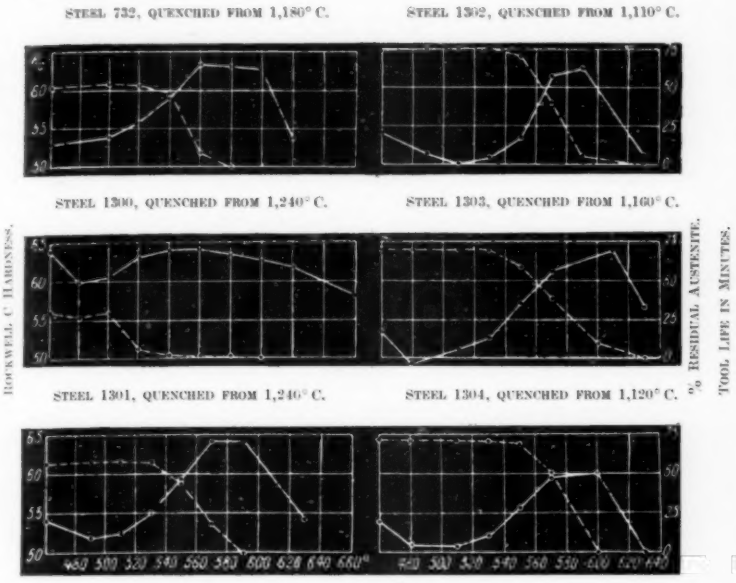

STEEL 732, QUENCHED FROM 1,180° C.
STEEL 1302, QUENCHED FROM 1,110° C.
STEEL 1300, QUENCHED FROM 1,240° C.
STEEL 1303, QUENCHED FROM 1,160° C.
STEEL 1301, QUENCHED FROM 1,240° C.
STEEL 1304, QUENCHED FROM 1,120° C.
ROCKWELL C HARDNESS.
% RESIDUAL AUSTENITE.
TEMPERING TEMPERATURE, ° C.

Fig. 3.—Secondary hardness and amount of residual austenite. of Steels 732, 1300, 1301, 1302, 1303 and 1304 when quenched in oil from optimum temperature at different drawing temperatures.

Continuous lines: Hardness in Rockwell C units. Broken lines: % residual austenite.

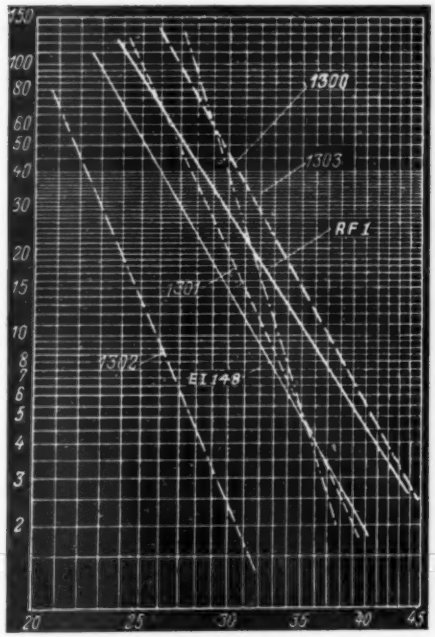
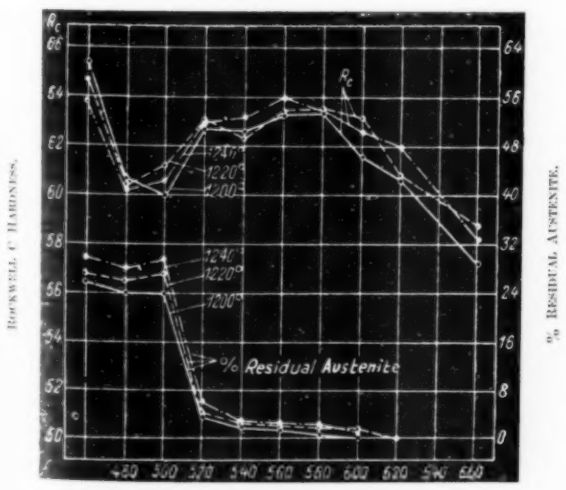


Fig. 5.—Tool life v. cutting speed of steels 1300, 1301, 1302, E.I. 184, and R.F. 1. Width of cut 3 mm., feed rate 0.4 mm. per revolution. Cutting edge: $\theta = 90°$, $\theta^1 = 12°$, $\gamma = 15°$, $\alpha = \alpha^1 = 6°$, R = 1.5 .mm

of residual austenite in steel 732 and 1303 shows that the increase in chromium content from 7·7 to 10·0% is accompanied by an increase in residual austenite. Lowering the molybdenum content from 3·86% in the case of steel 1303 to 2·02% as carried out in steel 1301, results in a decrease in the amount of residual austenite. The substitution of vanadium by titanium as carried out in steel 1304, as compared to steel 1303, is seen to have the result that already with the comparatively low hardening temperature of 1,160° C., when quenching in oil, the steel retains its purely austenitic composition. In this connection it is of interest to note that steel E.I. 184 (see Table IV) has a residual austenitic content of 60% when quenched in oil from 1,200° C.

With regard to residual austenite content, Fig. 2 shows the characteristics of steel 1300 to be outstanding, as in this steel the residual austenite amounts to only 25–32%, this percentage varying but little with the hardening temperature. This is due to its small chromium content of 4·49% and its comparatively high-vanadium content of 2·21%. Concerning the microstructure of steel 1300, it is reported that with all hardening temperatures, a fine-needled martensite is obtained, and the microstructure is said to be remindful of a typical high-tungsten high-speed steel. This is in contrast with the steels 732, 1301, 1302, 1303, and 1304, which were found to contain rather coarse-needled martensite plus coarse austenite. Drawing temper of one and the same sample at gradually increased temperature, enabled the establishment of the temperature interval of drawing versus (secondary) hardness. The time of drawing at each temperature was 1 hour.

Fig. 4.—Influence of drawing temperature upon hardness and amount of residual austenite of steel 1300, with oil quenching from 1,200°, 1,220°, and 1,240° C.



In Fig. 3 are shown both hardness and percentage of residual austenite as function of the drawing temperature in the case of quenching from the optimum temperature of the six steels investigated. It is seen that steel 732, after quenching from 1,180° C. and drawing at 560–600° C., gives a hardness of 63·5–62·5 Rockwell C. After three times drawing at 560°, 570°, and 580° C. for 1 hour duration each time, a hardness of 65 Rockwell C. was found.

Steel 1300 behaves differently in so far as transformation of the residual austenite into martensite takes place after drawing at considerably lower temperature. Referring to Fig. 4, it is seen that test-pieces quenched from 1,200°–1,240° C. contain almost no residual austenite when drawn at temperatures above 520° C. Another outstanding feature of this steel is the high stability of its martensite against repeated heating. In spite of the fact that with a drawing temperature of 520° C. the residual austenite is practically insignificant and repeated drawing cannot therefore increase the hardness, the hardness of this steel remains high, even after drawing at 620° C. Thus the steel permits of a wide interval of heating for hardening, extending from 1,200°–1,240° C. with a high secondary hardness from 62–63 Rockwell C.

In another series of tests, conducted with a view to ascertaining the stability of the various steels against softening, the samples were hardened by quenching in oil from optimum temperature followed by immersion in liquid air, thus transforming a considerable portion of the residual austenite into martensite. By observing the change in hardness with varying drawing temperatures, it was thus possible to estimate the stability of the material. Judged by their stability, the steels range as follows (from high to low): Steel 1300, 1303, 1301, 1302, and 1304. It is also stated that the stability is seen to be adversely influenced by the replacement of vanadium by titanium. Again, it was

found that when hardened from 1,220°–1,240° C. and subjected to triple drawing at 560° C. for periods of 1 hour each, the microstructure of steel 1300 consists of fine-needled martensite, and reminds of the microstructure of a high-tungsten steel.

In Fig. 5 is charted the tool life on a logarithmic scale against the cutting speed for various of the steels investigated. It is seen that again steel 1300 proved to be the most stable, exceeding even steel R.F. I. Up to a cutting speed of 31 metres per min., steel 1303 proves superior to steel R.F. I, while this position is reversed at higher speeds. The steepness of the characteristic is seen to be smallest with steel R.F. I.; it is somewhat greater for steel 1300, while steel 1303 possesses the steepest characteristic. As regards the tool life at low cutting speeds, wear endurance must be considered the vital factor, while in the case of high speeds with strong heating of the cutting edge, the red hardness of the steel must be the criterion. Wear endurance is obviously increased with the chromium content, therefore cutting tools of steel 1303 containing 10% chromium show high endurance at low cutting speed. Vice versa, highest endurance at high cutting speed characterises steel 1300, as this of all tested steels possesses highest resistance to softening.

From the comparison of steel 1303 with steel 1301, it is evident that a reduction in the molybdenum content from 4·2 to 2% leads to a deterioration in cutting properties. That replacement of vanadium by titanium is of a highly adverse influence upon the cutting properties of a steel, is exemplified by a comparison of the results obtained with steels 1302 and 1301 respectively. This holds true in even greater measure, for steel 1304 (not shown in Fig. 5) in which the vanadium content of steel E.I. 184 is largely replaced by titanium.

A special series of shop tests with steels 1300, 1301, and 1303 were also made at the Automobile Factory Stalin. The task consisted in the machining of a normalised chromium steel of 285–255 Brinell. All steels stood up very well at the cutting speed of 15·3–11·7 metres per min. with steel 1300 giving the best results. Under conditions of this kind, these low alloy steels were found to offer a highly satisfactory substitute for the high-tungsten steel R.F. I.

Its excellent cutting properties, ease of forging, comparatively low residual austenite content after hardening, low cost of manufacture, and complete freedom from tungsten, are responsible for the large scale introduction of steel 1300. At the Electrostal Works, this steel is manufactured in a 3·5-ton electric furnace, the analysis being 1·02% C, 5·26% Cr, 3·32% Mo, 2·3% V, 0·31% Si, and 0·31% Mn. Forging and rolling of this steel must be carried out between 1,130° and 950° C. After mechanical working, sizes over 40 mm. across should be heated to 760°–780° C. for 2 hours, in order to avoid the occurrence of fissures. Subsequent cooling can be carried out in air. Softening is best done at 900° C. with subsequent cooling to 700° C., with a cooling rate of 30° C. per hour, or at constant temperature of 760°–780° C. for 2 hours, with subsequent cooling in air. Where recrystallisation is not required, a treatment at 820°–840° C. for 2 hours is recommended. Hardening should be carried out by heating to 1,230° plus or minus 10° C., and quenching in oil; but for large tools of complicated shape, heating in potassium nitrate is recommended. The steel should be held at the hardening temperature for about the same length of time as usually employed with high-tungsten steel. After hardening, the hardness should be 60–63 Rockwell C, while the amount of residual austenite should approximate 30%. Drawing must be done for 1 hour at 560° plus or minus 10° C., the resultant hardness being about 64 Rockwell C.

SIXTEEN gold nuggets, three of which weigh between 70 and 129 grms. (about 2¼ oz. and 4 oz. Troy) have been found by a group of prospectors at Nizhny-Tagil, in the Urals, while working on an abandoned goldfield.

Forthcoming Meetings

THE INSTITUTE OF METALS.

BIRMINGHAM SECTION.

Jan. 2. "Hardness Testing, or the Investigation of Failures," H. O'Neill, M.Met., D.Sc.

„ 14. "Recent Developments in Magnetic Materials," by F. Kayser, Assoc.Met.

INSTITUTE OF BRITISH FOUNDRYMEN.

LANCASHIRE BRANCH.

Jan. 11. "Sands," by W. Y. Buchanan.

BURNLEY SECTION.

„ 14. "Some Interesting Small Problems," by A. Jackson.

SCOTTISH BRANCH.

„ 11. "Apprentices and Foundry Planning," by Jame Arnott.

WEST RIDING OF YORKSHIRE.

Jan. 11. Annual Dinner and Dance.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

Jan. 17. "Optical Instruments: with Particular Reference to Large Astronomical Telescopes," by G. E. Manville.

THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS OF SCOTLAND.

Jan. 14. "District Heating," by D. V. H. Smith.

The Metallography of Inclusions in Cast Irons and Pig Irons

(*Continued from page* 42)

is a good one, and it is still further improved by compounding—furnace-slag inclusion and moulding-sand inclusion. However, in the case of the particles described in this paper, it is obvious that the terminology is not all that is to be desired. Perhaps with the exception of the cyano-nitrides, all the particles dealt with are at least partially soluble in molten metal at the normal pouring temperatures.

Portevin and Castro have also shown how difficult it is to subdivide "inclusions" into metallic and non-metallic groups, and they have suggested that the following arbitrary classification could be made:—

Inclusions: Silicates, aluminates, oxides and sulphides.
Metallic Constituents: Nitrides, carbides (borides and perhaps phosphides).

This grouping would be very difficult to apply to cast iron, since the only metallographic inclusions would be the sulphides. Now, the blue-pink "inclusion" described in Group II of this paper is largely titanium sulphide, but it probably also contains a fair amount of dissolved titanium carbide which is presumably a metallic constituent. In this context, it is interesting to note that Portevin has made the very important point that the idea of an impurity or detrimental element is entirely relative and variable, and it would seem possible to extend this conception to the term "inclusion."

Inclusions have been stated to be the cause of a number of obscure phenomena exhibited by cast iron, and it has been implied that they have properties peculiar to themselves. A careful metallographic consideration of all the particles dealt with indicates no properties, and, what is more important, no modes of formation peculiar to these particles which are not exhibited in an entirely analogous way by the major phases of the cast-iron microstructure. It would seem, then, that the essential difference between these particles and the remainder of the metallic phases is the fact that the former occur in much smaller quantities. With this point in view, it is suggested here that these particles could be called "minor phases" to great advantage. This terminology has not so many misleading implications as the one already in use, and is likely to prevent the formation of prejudices and biased opinions when the properties of these small particles are being investigated or discussed.

Developments in Zinc Alloy Castings

By E. E. Halls

Much research has been applied to all phases of zinc alloy die-casting technique in recent years, and the progress achieved in this direction and in the development of reliable alloys has gradually removed the suspicion with which zinc alloy castings were viewed in the past. To-day, a relatively small range of these alloys has become commercially established, each with its specific advantages and claims for particular applications. In this article these alloys are discussed, and the problems associated with their use in the production of castings are considered.

FOR quite sound reasons—namely, disastrous early failures—zinc alloys as the base for cast components have been viewed with much suspicion for the last twenty or thirty years. During this time, suspicion has become prejudice in this country, so that until the last year or so zinc alloys have not been acceptable to general engineering, and their utilisation has been confined to a relatively restricted range of articles required competitively in large quantities. The automobile industry is typical of the more progressive groups, which have taken advantage of the possibilities of zinc alloys for their components, carburettor parts, instrument cases and accessories, door handles and radiator mascots being among the articles die-cast. In America, on the contrary, much development and research have been extended over many years, covering all phases of zinc alloy die-casting technique, during which period the alloys have been gradually adopted and confidently employed in practically every industry using metal products. But it is stressed that this condition of affairs does not mean indiscriminate practices in any way ; rather that industrial practice is strictly guided by sound technology.

In point of fact, a small range of zinc alloys has been commercially established, all with the same general attributes, each with its specific advantages and therefore claims for particular applications or service conditions, and each perhaps with some limitations. They serve industry while research goes on. They are of relatively closely limited composition, not only with respect to the percentages of main alloying elements, but of even greater importance with regard to permissible impurities and their quantity. Thus it is seen that the outlook on each side of the Atlantic is entirely different. In America, early failure of zinc alloys stimulated efforts to seek the cause, and as a result sound zinc alloys, a knowledge of what they should contain and what should be avoided, and also test methods for their soundness, have been established, accepted on their merits, and given entire satisfaction.

In this country, progress, soundness of outlook and opportunism have been entirely lacking. Moreover, there has been, in the writer's opinion, an inexcusable sluggishness to take advantage of the American experiences and published information. As a result, the few users of castings who wish to be in the forefront with fabrication methods are still asked to accept something " just as good," if this expression may be used, when they specify alloy of the proved type. The position, however, is rapidly changing for two reasons. Firstly, use of the light alloys for the majority of their mundane applications can no longer be justified under war emergency conditions, and zinc alloys are the only logical substitute. Secondly, production rates must soar while economy in machine loads must be exercised ; as a result, engineers have to take every possible advantage of die-casting.

Zinc alloys afford just that little extra advantage that convinces the most conservative. It is unfortunate that all the virgin aluminium required for the large quantities of alloy involved cannot be granted, and that a portion of secondary metal has to be employed for some grades of alloy, if only from the psychological angle. However, the forced acknowledgment of zinc alloys as engineering die-casting materials, the official insistence upon the right grades of alloy and their proper handling in the foundry to give uncontaminated castings, will inevitably assert its influence by the sound results achieved, so that in the post-war period the prejudice remaining should not be towards zinc alloys as a whole, but directed only against those not conforming to recognised standards.

The fault with the early zinc alloys lay in the fact that they were virtually developed from type metals, and comprised zinc, containing high contents of tin and copper, with often the inclusion of lead. They were subject to intercrystalline cracking which tended to develop rapidly with premature disintegration. They were also susceptible to growth and so, dimensionally, were notoriously unstable. Setting off, therefore, from the basis that zinc base metals suffered from these two objections, rather than trying to obscure the defects, research has been directed towards discovering the agencies that promoted such deterioration with a view to their complete elimination. At the same time, work covered the alloying elements in order to determine those necessary and the optimum quantities, all this having reference firstly to the serviceability of the article, and secondly to the practical problems in the foundry.

Regarding impurities, it has been established that cadmium, lead and tin are the fatal poisons, and that these, tending to segregate at crystal boundaries rapidly cause cracking and disintegration. They can be safeguarded against in the original alloy billets, beyond which it is the duty of the foundry to see that no possible contamination enters during casting. Pots, goose necks, and all machine parts must be kept scrupulously clean, with no possible entrance of other alloys. Likewise, scrap should not be returned unless guaranteed, and rejected castings viewed with suspicion, particularly if they contain metal inserts e.g., free-cutting brass screws, bronze bushes, etc. Likewise, cadmium-plated or tin-coated inserts should never be called for, as inevitably traces of these coatings enter the alloy, at least locally. Iron is another impurity due to unavoidable pick-up from machines, pot, ladle, and die. It is not seriously detrimental in limited amounts, but excess may cause local embrittlement, and reduce surface resistance to corrosion.

Alloying Elements

Modern alloying elements are aluminium, copper, and magnesium. Aluminium is essential, its optimum concentration being 4%. It helps the caster, improves life of the tools, and adds to mechanical strength of the alloy. The first is done by improving fluidity and that nebulous though positive factor of castability. The second it achieves by reducing the rate of dissolution of iron from melting pots and goose necks. The third it produces by refining the grain size, although if present in excess it can reduce resistance to impact. Copper is claimed to be an essential element by many die-casters, but this is not a fact. The practical effect is a marked improvement in castability, with copper up to 1 to 1½%. It tends to reduce intercrystalline deterioration, and was at one time essential for this, but the availability of super purity zinc has changed this position. It is favourable in improving tensile strength, but it can operate unfavourably upon dimensional changes with time.

Magnesium is primarily required for suppressing intercrystalline corrosion, and in conjunction with the high purity zinc eliminates the need for the inclusion of copper to this end. The straight zinc-magnesium-aluminium alloys

are the most dimensionally stable so far developed. In the absence of copper, magnesium in some cases does detract from the quality of castability, hence the close limits upon its content ; but in excess it also promotes hot shortness. The magnesium percentage being so low renders it imperative that it shall not be lost during die-casting, and for this reason overheating, excessive time of heating, and the return of scrap must all be given the most careful attention. The latter becomes something of a problem if not organised from the outset, because scrap is inseparable from good casting technique and economics demand its re-use.

Factors Ensuring Soundness

For the provision of good smooth surfaces and ensuring maximum soundness internally, generous vents on the die must generally be given, with correspondingly higher scrap. It is recommended that as castings flow forward along the production line, scrap from fettling operations and rejections should continuously pass in the return direction. This avoids accumulations with the consequent greater possibility of contamination, encourages each machine to use its own scrap, and minimises the possibility of admixture of alloys, as well as helping to maintain composition and physical condition as uniform as practicable over a long run. Again, remelting of new scrap is easier and cleaner than that of old scrap, because of lesser dust and dirt contamination and little surface oxidation. Fluxes must not be used, because they invariably result in losses of aluminium and magnesium by interaction with acidic or halogenated bodies, and loss of magnesium initially present in such small quantities is very harmful. Failure of castings to pass steam ageing test requirements has on more than one occasion been traced to this fault.

TABLE I.

TYPICAL ANALYSES OF THE EARLY UNSATISFACTORY ZINC CASTING ALLOYS.

Sample No.	Composition, %.				
	Tin.	Copper.	Lead.	Aluminium.	Zinc.
1	10·2	4·1	2·2	1·5	82·0
2	9·5	3·3	2·7	2·3	82·2

Some Alloys and their Properties

The patented series of alloys under the trade name of Zamak in America and Mazak in this country grew with the development work noted above, and have rightly grown to be regarded as the standard of reference for sound zinc alloys. Their compositional, mechanical and physical properties are all clearly defined, as well as their stability in terms of change in strength or in dimensions with ageing. Table I shows the composition of typical castings of old-time composition, which proved a failure, due to disintegration in service. This is given to contrast with the Mazak compositions given in Table II and with the typical modern alloy compositions shown in Table III, which closely follow the Mazak formulations without the magnesium constituent, without the same guarantee for super purity zinc and meticulous care respecting impurities, and assurances with respect to behaviour from ageing in service conditions.

TABLE II.

COMPOSITIONAL VALUES FOR THE MAZAK SERIES OF ZINC ALLOYS.

Alloy No.	Composition, %.								
	Aluminium.			Copper.			Magnesium.		
	Nom.	Max.	Min.	Nom.	Max.	Min.	Nom.	Max.	Min.
2	4·1	4·3	3·9	2·7	2·9	2·5	0·03	0·05	0·02
3	4·1	4·3	3·9	Nil	0·03	—	0·04	0·06	0·03
5	4·1	4·3	3·9	1·0	1·25	0·75	0·03	0·05	0·02
6	4·1	4·3	3·9	1·25	1·50	1·00	Nil	0·005	—

Maximum impurities in all alloys, Iron 0·075, Lead 0·003, Cadmium 0·003, Tin 0·001. Remainder in all alloys, Crown special zinc, 99·99+.

It will be seen from Table II that the No. 2 alloy is a high-copper content composition ; it has high qualities of castability and high strength, but suffers in elongation, impact strength, and slightly in dimensions upon ageing. No. 3 alloy, copper free, tends to improve markedly in elongation and impact, and to lose slightly in tensile strength : dimensionally, it is most stable with negligible changes. Alloy No. 5 is a compromise with low-copper content to retain maximum castability, showing some loss in impact upon ageing and some dimensional change. Alloy No. 6 is a further compromise to meet the demands of a market where the possibility of slight tendency to intercrystalline cracking and close retention of dimensions are of no importance.

TABLE III.

COMPOSITIONAL VALUES OF OTHER TYPICAL MODERN ZINC ALLOY CASTINGS.

Sample No.	Composition, %.	
	Aluminium.	Copper.
1	4·32	Nil
2	4·90	0·95
3	3·80	Nil
4	4·11	2·36
5	4·00	0·10
6	4·15	0·26
7	4·09	2·35
8	3·55	1·03

TABLE IV.

AVERAGE MECHANICAL AND PHYSICAL VALUES FOR MAZAK ALLOYS.

Alloy No.	2	3	5	6
Tensile strength, tons/sq. in.	21	20	20	19
Elongation % on 2 in.	5	4½	3	5
Impact strength, foot-lb.	19	20	17½	22½
Specific gravity	6·7	6·6	6·7	6·7
Melting point, ° C.	380	380	380	380

Typical average mechanical and physical values for these alloys are given in Table IV for guidance in comparing with other established alloys.

War emergency has influenced the position of availability in this country, as a result of which the Mazak 3 alloy is still obtainable in no way modified from the original proved formulation, but the same virgin grade of aluminium is not obtainable for the other alloys. In order to distinguish clearly this change in affairs, a new alloy is marketed under the name Durak, covered by patent. This corresponds to the same close compositional limits as Mazak 5, to the same stringent restrictions on the harmful impurities, and virtually its performance can be regarded as the same as No. 5. Consequently, all rigorous service demands should be catered for by No. 3, and the less stringent ones by No. 5.

It is seen from the foregoing that composition is critical, and it should therefore demand inspection control by analysis of batches of castings. This is practicable but tedious, and involves much skill for small amounts of magnesium (an essential ingredient) and for the minute but critical impurities. Actually, many inspection departments prefer a quick analysis for aluminium and copper, these determinations being straightforward, and a steam ageing test to cover the other features. This test comprises exposure of a number of samples, from the batch to an atmosphere of steam, 100% humidity at 95° C., for a continuous period of 10 days, day and night. The equipment required is simple, although special. It uses a well-lagged tank lined with copper or Monel metal. A reservoir of water at the base is heated by electrical units automatically controlled from a point in the atmosphere above. A good fitting cover is required, with external indication of temperature and a means of maintaining water level. No organic matter is permitted within the apparatus, and specimens are suspenced from glass rods in the atmosphere, using zinc-coated or aluminium wire.

The steam test discerns different compositions by the amount of dimensional movement, selected dimensions being measured accurately before and after test. Mazak 3 alloy will not give a movement of more than 0·001 in., whereas Nos. 2, 5, and 6 will give rather more. Loss of magnesium on casting will cause an increase in movement. It is pointed out that dimensions not unduly broken by holes and such like should be chosen, and the same movement must be allowed on dimensions of less than 1 in. The test shows porosity and air inclusions from bad casting or poor design because undue expansion occurs and when fractured black cavities are revealed. It shows adverse contamination by distortion, cracking, and a tendency to laminate. Consequently much can be learnt from the test by dimensional check, visual examination and fracture, and batches represented by the specimens can confidently be accepted if the samples withstand the conditions satisfactorily.

Users of zinc castings, even when selecting Mazak No. 3, have still another safeguard against permanency of dimensions in service where dimensions are exceptionally critical. This comprises an ageing heat-treatment and the temperature can be from 70° to 100° C., with a corresponding time from 20 to 30 hours. This treatment only applies to Mazak No. 3 alloy. It produces almost immeasurable dimensional change, but settles that small initial shrinkage of the material. It should therefore be done prior to any machining to critical dimensions—e.g., drilling of holes or milling of faces.

The disadvantage of zinc alloys when compared with the light alloys is almost solely with respect to density. From the production angle, much lower casting temperatures are entailed (400°–425° C., as against 600°–700° C. for aluminium). Considerably less solution of iron from dies and less erosion of them occurs. Consequently, longer runs are possible prior to correcting tools, which thereby have longer life with a resultant greater accuracy and better surface finish. Also, operating conditions are accordingly more comfortable. Zinc alloys have a short solidification range, and a narrower range through which to cool from solidification than do the aluminium alloys. From all these angles, zinc approaches the ideal for a die-casting alloy for intricate components, for important dimensions, and for clear, sharp outlines. Exceedingly thin sections can be die-cast and fine print can be reproduced in raised characters, and metal "labels" of this type down to 0·020 in. thickness have been used. For miscellaneous components of irregular configuration, no general rule can be given for minimum thickness of any particular section, but $\frac{1}{16}$ in. serves as a general guide. Where tappings are involved, the size of hole is to some extent a determining factor, and always sufficient thickness for at least two complete threads must be provided. For projections, the maximum possible root radius is always advisable. Again, as much metal as possible should be allowed in design around holes, as otherwise there is a marked tendency for air locks during casting, with porosity and consequent loss of strength.

The mechanical values for zinc alloys have already been referred to in Table III. It will be noted they are superior to the average values for the aluminium light alloys, tensile strength and elongation being about double, and impact four to six times as great. They are harder, too, usually ranging from 60 to 100 d.p.n. Relative to mechanical strength, a series of test values for strength of tapped holes is of interest. Mazak No. 3 alloy castings were used, and, for comparison, hard temper white brass sheet (copper 60%, zinc 40%, hardness 160 d.p.n.). A range of B.A. sizes of steel screw were employed in a range of thicknesses of the two metals. The direct pull to strip the threads (tensile strength) was measured, and the torque to overturn the screw (unless it broke at head or thread) was also determined. Results are given pictorially in Figs. 1 and 2. From these it can be seen that the zinc alloy can be relied upon to give at least half of the mechanical strength of hard brass. It has already been indicated

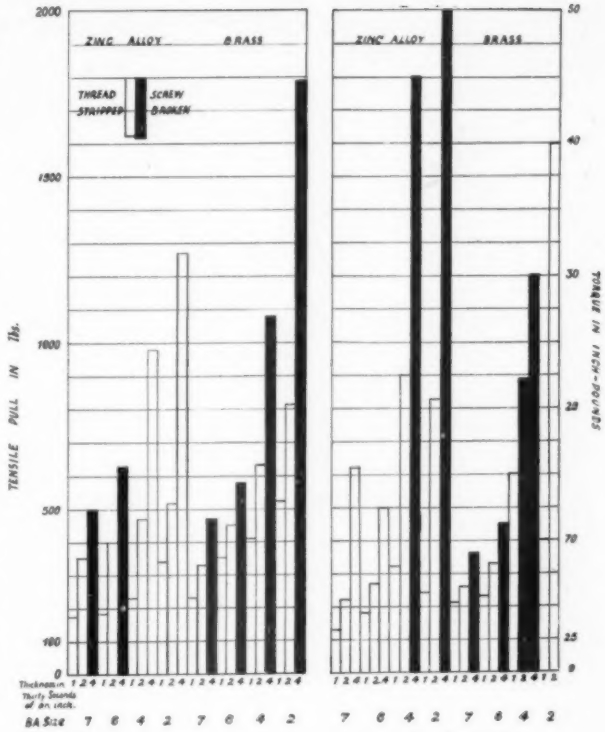


Fig. 1.—Tensile. **Fig. 2.—Torque.**

A comparison of thread strengths in zinc alloy and in brass.

that the mechanical properties are retained upon ageing, so no doubts as to utility and performance need remain.

Surface Condition and Finish

The finishing of zinc alloys by enamel and electro-plate will be discussed in later issues. One relevant aspect, however, is appropriate at this stage. This refers to surface condition and finish. It has already been stated that little wear occurs on tools, and therefore dies initially well finished retain this conditionally. Dies must be well vented and brought together with adequate pressure. Long experience in the States has caused the evolution of new pressure die-casting machines to meet the new conditions imposed by zinc—namely, clean, rapid and accurate working. In one of these, the die is closed by an initial pressure, and this is automatically ensured before the final pressure forces the metal into position. In this way, improper closing of the die with resultant splashing of metal is avoided, the possibility of metal getting between mating surfaces where it is not intended is eliminated, and general safety-first conditions are assured. In conjunction with this machine, and where both configuration of the part and quantity required permit, a designedly thick "flash" is aimed at, and this is subsequently sheared off very accurately in a blanking tool. This, combined with high density, ensures minimum of polishing for electro-plate finishes, such as bright chromium. It also ensures no possibility of air entrapment which can cause flaking of surfaces with consequent additional finishing troubles.

Machining

Apart from fettling, zinc base die-castings in general are ready for assemblage or for decorative and protective finishing. Upon occasion, minor machining operations are, however, necessary, or adaptation of a casting from an existing tool by slight modification may be a matter of economics. The zinc alloys, relatively soft, present little difficulty, and much machining is done without lubrication. At the same time, zinc does tend to build up on tools and cause seizing, and for all speed operations proper lubrication is advocated. The chief machining operations include tapping of small holes, which may be as small as

9 or 10 B.A. size, and drilling of small holes. Again, milling for accuracy of flatness of one face relative to another may be entailed. In using lubricants, however, thought must be given to their subsequent removal because traces of oil or grease are very harmful to the proper adhesion of finish. Broadly speaking, a liquid lubricant easily removable by solvent, preferably by trichlorethylene, since this is a commonly employed degreasant, should be selected. "Solid" fats and waxes should be avoided in every case, and this particularly applies to tallow and beeswax, which are often chosen for efficiency and convenience in application.

TABLE V.

CHARACTERISTICS OF LIGHT MINERAL BLENDING OIL AND OF PARAFFIN OIL.

Mineral Blending Oil.		
Physical.		
Viscosity, Redwood, seconds at—		
70° F.		200
140° F.		51
212° F.		33
Specific gravity at 60° F.		0·895
Specific heat		0·58
Flash point, °F. (open)		280
Chemical.		
Acid value		Nil
Saponification value		Nil
Iodine value		12
Ash, %		Nil
Paraffin Oil.		
Specific gravity at 15·5° C.		0·820
Boiling range, °C., % by volume :—		
180–190° C.	5	
190–200° C.	10	
200–210° C.	21	
210–220° C.	21	
220–230° C.	20	
230–240° C.	14	
240–250° C.	8	
Above 250	1	
	100	

Note.—A 50/50 mixture of the above provides a good cutting coolant for drilling.

For drilling, mixtures of lard oil or machine oil and paraffin, turpentine and paraffin, and soluble oil are commonly used. The writer prefers to use a 50/50 mixture of paraffin oil and mineral blending oil of characteristics given in Table V, or for the more difficult cases ordinary good quality sulphurised cutting oil (see Table VI) thinned 1 part with 4 parts of the blending oil. For tapping, a special tapping oil, comprising a fixed oil, such as lard oil, in light mineral oil is recommended. Examples of this type of lubricant are given in Table VII. Soluble oil emulsions are not recommended, owing to the difficulties of cleaning off the soapy oil emulsion. If one is employed, it must be followed by an alkaline clean (e.g., 4 oz. of sodium metasilicate per gallon), ensuring complete removal.

TABLE VI.

CHARACTERISTICS OF STRAIGHT SULPHURISED CUTTING OILS.

	Type No. 1.		Type No. 2.
Physical.			
Viscosity, Redwood, seconds at—			
70° F.	620	..	730
140° F.	71	..	75
212° F.	24	..	43
Specific gravity	0·930	..	0·928
Specific heat	0·53	..	0·52
Flash point (open), °F.	352	..	338
Chemical.			
Acid value, mgms. KOH/gm.	5·9	..	3·3
Saponification value, mgms. KOH/gm.	30	..	35
Iodine value	16	..	22
Sulphur content, %	0·6	..	1·8
Ash on incineration, %	Nil	..	Nil

Note.—Type 2 preferred for higher sulphur content and higher viscosity when warm.

Attention in machining must be given to clearance for chip removal. Cutting angles must be correct, tools keen, speeds generally high, and feeds slow. It is worthy of note that holes can be punched in thicknesses up to $\frac{1}{8}$ in. providing there is the surrounding land and the metal is fully supported on the bottom tool.

TABLE VII.

CHARACTERISTICS OF SPECIAL TAPPING OILS.

	Type No. 1.		Type No. 2.
Composition, %.			
Lard oil	25	..	50
Wool fat	75	..	25
Mineral oil	0	..	25
	100	..	100
Acid value, mgms. KOH/gm.	2·7	..	1·3
Saponification value, mgms. KOH/gm.	132	..	78
Ash on incineration, %	0·02	..	0·01
Viscosity, Redwood, seconds at—			
70° F.	240	..	205
140° F.	70	..	61
212° F.	42	..	36

Note.—Type No. 2 preferred for greater fluidity and adequate fatty oil content; Type No. 1 would withstand 50/50 dilution with mineral blending oil.

The fillip given by the automobile industry to zinc castings for ornaments, handles, stone guards, and miscellaneous parts has extended to all engineering industries. Ornamental cast-iron frames and grills are substitutable by zinc. Buckles and clips, buttons, ornaments, clock frames, desk accessories—all miscellaneous articles can be made in this way. The electrical industries now use zinc alloys for frames for switches and automatic apparatus, for plug bodies and terminal connectors, for supporting brackets and base-plates, for dust covers, and so forth. Applications are legion, but the alloy must be properly chosen and covered by inspection test, and the component should be thoughtfully designed to secure the best from the many advantages of zinc alloy die-casting.

Sintered Alloys of Boron Carbide and Their Applications

BORON carbide is harder than silicon carbide or fused alumina; in the fused condition it is more brittle than copper or nickel and their alloys. Some time ago it was found[1] that boron carbide readily alloys with these and other common metals after heating to about 2,000° C. Examination of the products after cooling reveals that the metal solidifies in the spaces between the boron carbide crystals. Maximum toughness is attained by using crucibles of magnesia or graphite crucibles lined with magnesia, ordinary graphite crucibles resulting in absorption of a percentage of graphite by the alloy to give a product which can be readily cut and worked.

A convenient method of working this type of boron carbide alloy is to convert it into powder and then rebond by sintering at a relatively low temperature ranging from 800° to 1,400° C.[2] The sintered compositions find application as abrasives and bearing surfaces. A typical abrasive mix comprises 80 parts of a boron carbide alloy containing 70% copper, which is thoroughly mixed, before sintering, with 10 parts copper powder and 10 parts diamond (80–140 mesh). For use as bearings the face of the alloy is subsequently lapped and polished to avoid abrasion.

A more recent development in this field concerns the production of fused compositions, in which a carbide of tungsten, molybdenum or chromium is associated with boron carbide as a separate crystalline phase. These are prepared[3] by simultaneous reduction of boron oxide in admixture with chromium oxide, etc., with carbon in a resistance type furnace. One used in the manufacture of silicon carbide or boron carbide itself is suitable, a conducting core of carbon being bedded in a loose granular mixture of the respective oxides and carbon. Abrasive masses are subsequently prepared from the reaction products by crushing, moulding to shape and heating until sintered or incipiently fused. Like the alloys with the common metals mentioned above, the boron carbide-chromium carbide and like masses have the property of forming a pasty mass when heated, which facilitates their working.

1. U.S.P. 2,124,538. The Carborundum Company.
2. U.S.P. 2,200,258. Carborundum Company.
3. U.S.P. 2,201,151. Carborundum Company.

Some Scientific Problems connected with Powder Metallurgy

By E. A. Bánó, Ph.D.

The application of powder metallurgy is still in its infancy, and more intensive research on the process would have a stimulating effect in promoting its development, and in this article some problems are discussed, the solution of which would effect progress.

THE technical importance which powder metallurgy possesses in these days need not be emphasised, and reviews on the possibilities of its application have been made in a number of publications; in fact, its application and development have been based mainly on experience which, to-day is considerable.

Investigations on the physical and chemical fundamentals of this process are scarce, or at least, little has been published about them; too little, indeed, and penetrating further into the fundamental phenomena which occur when metal powders consolidate under the influence of pressure or heat, or both of them would not only be to the benefit of powder metallurgy itself, but would also have a stimulating effect upon other branches of scientific research.

In the following a selection is made from the many examples which could be cited, and they clearly point to what amount of research work could be done.

There is little agreement on the question why compressed metal powders keep together even if not subjected to any intended heat-treatment, however trivial it may appear to the powder metallurgist to compress metal powders to briquettes in a suitable mould out of which these compacts can then be taken, in most cases without special precautionary measures, and showing surprisingly high solidity. Ch. Hardy[1] has given us some idea on that subject, but otherwise little attention has been dedicated to that question since the publication of W. D. Jones' book on "Powder Metallurgy."[2]

Hardy suggests that friction caused by the act of compression is responsible for generating an amount of heat which might enable the particles to weld together. Furthermore, he assumes that the particles owing to the method by which they are usually produced possess a very clean surface. This assumption, however, has by no means been proved correct, and it is doubtful whether in the majority of cases it is permissible at all. Whilst he admits that with particles of the same metal this welding effect takes place only at the surface of the particles he presumes that in case of pressing a mixture of powders—e.g., copper and tin, such an amount of heat can actually be produced which might be able to perform alloying between the particles concerned, and in this connection he speaks of "migration of atoms," and "atomic welding"; indeed, an attractive comprehension, which might be the beginning of a series of valuable investigations!

If friction really plays an important part in the consolidation of metal powder accumulations, then strength of the pressed compacts or perhaps better the amount of molten or liquid phase produced ought to depend on the shape of the mould for a given quantity of powder; furthermore, it will depend not only on the absolute pressure exerted but on the speed at which it acts, not only on the particle size, but also on the particle shape and on the grain size distribution of the powder employed.

Tensile tests on pressed compacts made from one or more powders in connection with microphotographs would surely bring forth interesting results. In this connection investigations should be made on the question whether particles after having been pressed together are mechanically interlocked with each other, in which case particle size would play the dominating part. The question if and how the original structure suffers from alteration or even destruction and of what nature the inner stresses are to which the particles are exposed should also be given attention.

The engineer or scientist who is familiar with the production of metalloceramic products is well conversant with the so-called presintering or prefiring process—i.e., a heat-treatment to which certain powder-metallurgical products are exposed prior to the sintering proper. The bar consisting of compressed tungsten powder shows higher solidity when exposed to a heat-treatment of about 1,000° C. for a certain period of time than one which comes right out of the mould. What takes place during such a heat-treatment? Is it that the processes involved are substantially the same as those which occur during the sintering close below the melting point? And is it permissible in the case of tungsten, for instance, to speak of plasticity as W. D. Jones[3] understands that term, and Comstock[4] discusses it? And does grain growth take place and recrystallisation? Here, too, microphotographs may offer some interesting conclusions.

Some light could be thrown upon the question as to what part recrystallisation plays in sintering phenomena by using—e.g., tungsten powder reduced in hydrogen in comparison with tungsten powder mechanically comminuted to the same grain size. A powder which has suffered from no mechanical treatment will most probably act in a way quite different from one which has been manufactured by a comminution process.

Or is it really films of impurities surrounding each single grain which, as Carpenter and Robertson[5] doubt, are supposed to be responsible for grain bond in general? If that be the case, particles of powders prepared in different atmospheres should combine with each other in different ways, and Goetzel's research on copper powders[6] represents an extraordinarily valuable contribution towards this problem. He found that copper compacts sintered *in vacuo* are superior in properties to those heat-treated in hydrogen. A comprehensive study of this paper is suggested. He entered a field which should now be properly explored.

Another interesting but well-known phenomenon is, that loosely-heaped metal powders, when heated, take on a certain amount of solidity without previously having been exposed to any pressure. Are the tensile properties of such structured agglomerations in any connection with the melting point of the metal powder employed, with the way in which it has been pretreated, and in this case are valid the same laws which hold good for compressed metal powders? Grube and Schlecht[7] have in a way dealt with that question as far as molybdenum is concerned, and they found that the temperature at which grain growth of molybdenum powder begins does not depend on the pressure applied, and is the same for loosely-heaped powder and for compacts pressed under 6,000 kg./cm.^{2} These results only prove the necessity of continuing investigations of that nature.

And, apart from that, can there be any essential differences observed other than greater porosity, particularly as regards grain growth, bond of grains and recrystal-

1 Ch. Hardy. "Nature of Bond in Powder Metal Compacts." *Metal Progress*, vol. 35, 1939, p. 171.
2 W. D. Jones. "Powder Metallurgy." Edward Arnold and Co., London, 1937.
3 W. D. Jones, *loc. cit.*
4 G. J. Comstock. *Metal Progress*, vol. 35, 1939, p. 343.
5 H. Carpenter and J. M. Robertson. "Metals." Oxford University Press, 1939.
6 C. G. Goetzel. "Structure and Properties of Powder Compacts." *Journ. Inst. Met.*, vol. 66, 1940, p. 319.
7 G. Grube und H. Schlecht. "Ueber Sinterung von Metallpulvern. *Z. Elektrochemie* (44), 1938, p. 367.

lisation? What could we learn from microphotographs showing sections of heaped powders heated at different temperatures? Do particles grow in different ways with and without having been subjected to preceding heat-treatment?

In the electrical industry so-called compound metals find use as contact materials on a large scale, and their main features have been discussed and thoroughly described in various publications and patent specifications. In the majority of cases tungsten represents the main constituent of such contacts, and it has become evident that different grades of tungsten put up different resistance against the influences of the electric arc. It has been proved that the life of such contacts and/or the load permissible for an assumed life depend clearly on the kind of tungsten grain employed, on its shape, its structure and the mechanical and thermal pretreatment. It is evident, that powder metallurgy in this field may have a stimulating effect on the question of relationship between corrosion and structure of metals, nature of the grain bonds, etc., in general and the conditions prevailing in an electric contact concerning arc resistance, interface resistance and the dependence on the structure of the contact and its pretreatment in particular.

W. D. Clark[8] has recently described how aluminium-tungsten-alloys for the purpose of studying the equilibrium were produced by adopting powder metallurgical methods. Powder metallurgy here points to a very promising aim indeed, and apart from the industrially well-known method of intermixing homogeneously metals which do not alloy with each other, this method opens interesting aspects for the merely scientific side of metallurgy. Several other equilibria may probably be investigated similarly—e.g., W-Ag, W-Zn, Mo-Ag, etc., etc.

Hence, the path leads further to the field of intermetallic diffusion in general, and the results which W. D. Jones achieved[9] with a series of powders give rise to the question why bodies produced from powdered alloys show properties superior to those produced from their powdered constituents.

In continuation of studying concentration-temperature equilibria would it not be interesting to look into pressure-concentration-temperature equilibria where powder metallurgy might be very helpful and might probably open aspects of an interesting nature?

A paper which has recently been published in the American journal *Metal Progress*[10] ought to be mentioned in connection with these considerations. In this paper the production of magnetic alloys by means of powder metallurgical methods has been dealt with. The main properties of these alloys and advantages we are not going to discuss here, but attention should be drawn to two interesting features—viz.:

(*a*) Dependence of permeability on grain size of alloy.
(*b*) Insulation of each individual grain by a ceramic material.

(*ad a*) Investigations and publications would most likely be very instructive. Permeability will probably not only depend on grain size merely, but on the shape and pretreatment of the grain as well.

(*ad b*) The intended mixture of metals and metal oxides, which, at such an amount of required homogeneity can probably only be achieved with the help of powder metallurgy, has here been carried out on a broad basis.

One will now ask for the essential differences between the combination of metal particles with each other and that of oxides and/or related materials (as they find use in the ceramic industry) with each other, and in pursuance of that, considerations on the essentials of the kind and nature of metal- metal-oxide binding will doubtlessly be led to fertile grounds through the help of powder metallurgy.

Increased Use of Aluminium Alloy Scrap for Aircraft Materials

By H. F. James (*Director of the Northern Aluminium Company, Ltd.*)

As a result of the urgent need for still further increasing the output of British aircraft, the most efficient utilisation of all available supplies of aluminium is now a matter of the greatest importance. The most remunerative step in this direction is to ensure that all good quality aluminium alloy scrap is recovered in an identifiable form for further use.

The magnitude of the quantities likely to become available can best be indicated by the fact that for every 100 tons of light alloy materials supplied for air-frame and engine production not more than 25 to 30 tons flies away in the completed aircraft.

Several British Standard Specifications relating to aluminium alloy products for aircraft construction have recently been relaxed in order to permit the use of scrap other than that of a manufacturer's own production. These modifications mark an important stage in the history of aluminium alloy manufacture, in that their introduction removed the sole remaining dividing line between the so-called "virgin" and "secondary" alloys.

For some years this division has been somewhat fallacious, except in the case of materials required to conform rigidly to British Standard Specifications. The increasing care taken in the segregation and remelting of light alloy scrap has permitted the introduction of much larger proportions of such scrap into good quality alloys. There are now no high quality aircraft alloys in which scrap is not, or cannot, be used.

There is no doubt that, so long as unwanted constituents in scrap are kept within the required limits by careful sorting and melting in clean furnaces under satisfactory conditions, the product is, in all respects, suitable for addition to melts consisting of virgin metal and production scrap from semi-finished forms, such as, for example, aluminium alloy sheets.

Before the war, scrap from specification materials in the form of sheet cuttings, forging trimmings, turnings, etc., was chiefly used in the manufacture of certain relatively low-grade casting alloys from which many of the light alloy castings employed in the motor trade were produced. Thus, before the previously mentioned modifications to specifications were introduced a danger existed that the practice might continue of degrading high-quality scrap, such as Duralumin sheet cuttings, by adding it to melts containing zinc, iron, silicon or other impurities in order to produce low-grade casting alloys. This would, of course, have resulted in a loss of aluminium for aircraft production of several thousand tons a year.

Immediately upon the outbreak of war, however, the use of aluminium was necessarily very severely curtailed, and it became obvious that all good quality scrap should be segregated and used again in melts of composition similar to that of the original sheet, rod or other material from which it was produced. Utilised in this manner, its intrinsic value is approximately equivalent to that of alloys of similar constitution produced from virgin materials. The percentage of such secondary material that can be added to melts is limited only by the supplies of segregated scrap available, and not, as has been the case hitherto, by the quantity of impurities allowed to mix with the scrap.

It is important that every ton of good quality scrap, conserved by careful sorting and melting, saves a ton of imported virgin metal, and the shipping space required to transport it to this country.

8 W. D. Clark. "The Aluminium-Tungsten Equilibrium Diagram." *Journ. Inst. Met.*, vol. 66, 1940, p. 271.
9 W. D. Jones. "Hotpressing of Metal Powders." *Met. Ind.* (London), 56 (10), 1940, p. 225.
10 V. E. Legg and F. J. Given. "New Magnetic Alloy of Powdered Metal." *Metal Progress*, 38, 1940, p. 284.

Some New Ferrous and Non-Ferrous Alloys

Their Composition and Uses

Brief information is given of a selection of ferrous and non-ferrous alloys recently developed in the United States.

THE development of new alloys in both the ferrous and non-ferrous metallurgical laboratories has proceeded with considerable vigour during the last year or two, and many patents have been granted for special alloys developed for specific purposes. Several of these are noteworthy as showing the trend of progress and brief reference is made to them in this review.

Ferrous Alloys

Corrosion-resistant iron alloys contain 28–30% nickel, 19–21% chromium, 2·7–3·2% molybdenum, 0·75–1·10% silicon, 4·5–5% copper, and up to 0·07% carbon. These alloys[1] can be hot-worked without difficulty and are exceptionally resistant to sulphuric acid in consequence of the presence of copper. Incorporation of the latter is facilitated by a combined silicon-molybdenum content not exceeding 5%.

Permanent magnets of the aluminium-nickel-iron type are prepared from a mixture of iron oxide, aluminium, nickel and a trace of zirconium. An alloy[2] containing 57·7% iron, 29% nickel, 13% nickel, and 0·2% zirconium is made by igniting in a graphite crucible a mixture of finely divided black oxide of iron, aluminium shot, nickel shot and zirconium oxide. An excess of the last ingredient must be used as some of the zirconium finds its way into the slag. The melt is chill-cast by pouring into unheated moulds and then magnetised in the usual way. Zirconium takes the place of a much higher percentage of cobalt.

Steel with good creep-resistance at high temperatures is made by substituting phosphorus for part of the molybdenum or tungsten generally considered necessary for this purpose.[3] A phosphorus content ranging from 0·08 to 0·6% is advisable for steels alloyed with one or more elements in the group comprising nickel, cobalt, silicon, titanium, zirconium, manganese and carbon. The total of such elements should not exceed 30%. These steels find application in the fabrication of oil-still castings and oil-cracking still tubes subjected to high pressures at temperatures exceeding 450° C.

Alloy steels with tungsten (or molybdenum), chromium and vanadium as principal alloy metals possess a fine grain and an improved creep ratio at high temperatures. They are suitable for valves, pipelines and high-pressure oil-refinery equipment operating at temperatures round 550° C. A typical alloy[4] will contain 0·15% carbon, 6% chromium, 1% tungsten (or 0·5% molybdenum), 1% vanadium, 1·25% silicon, 0·05% sulphur, and 0·05% phosphorus.

Copper Alloys

Hot- and cold-workable alloys contain silicon, manganese and nickel.[5] A crucible is charged with proportions of these metals to give a final content of 90–98% copper, 1–7% silicon, and 0·10–0·75% manganese. Enough nickel is then added to the melt to give a final content of 0·25–10%; also enough iron to give 0·5–0·75%. The mix is melted at above 1,150° C. and poured at 1,120–1,140° C. to ensure sound castings. These alloys are used for water and chemical tanks, paper mill and textile equipment and turbine blading.

Hard, tough, ductile and springy alloys are made by melting 87–90% copper, 9–13% zinc, and 2–4% tin in a crucible with addition of less than 2% manganese as a flux.[6] They find application for electric switches (very high conductivity), fuse clips, springs and sash chains. Their hardness does not suffer by exposure for several hours to a temperature of 250° C.

By including a relatively high proportion of zinc in copper-lead alloys it is possible to effect rapid deposition during welding. Slags rise rapidly to surface of the welding puddle and so make possible the use of a relatively large and deep puddle. Alloy welding rods on this basis contain 12–15% lead, 8–10% tin, 10–15% zinc, 0·08–0·2% silicon, and the balance copper.[7]

Dezincification of copper-zinc alloys is found to be hindered or prevented by a small proportion of silver. Small quantities of other elements may be present (up to 3·5% of tin, aluminium, lead, iron, manganese or silicon), in an alloy[8] composed of 58–85% copper, 0·005–2% silver and the rest zinc. The superior corrosion resistance makes these alloys suitable in the construction of marine fittings.

Aluminium Alloys

A denser grain structure and better casting and machining qualities are conferred upon aluminium base alloys containing iron and antimony by addition of a tungsten group metal (tungsten, molybdenum or uranium), or a vanadium group metal (vanadium, columbium, tantalum), or a metal such as beryllium, boron or zirconium. Limits specified for ingredients are 4–10% copper, 3–8% silicon, 2–10% iron, 0·5–15% antimony, 0·25% magnesium. The alloys serve for manufacture of pistons and cylinder heads.[9] An aluminium alloy containing 1·35% copper, 1·35% manganese, 0·17% titanium, and 0·25% magnesium was difficult to cast. This defect was overcome by adding up to 0·25% tungsten.[10]

Magnesium Alloys

A trace of calcium is advantageous in magnesium alloys containing aluminium, zinc and manganese. It permits of more rapid solution heat-treatment at a higher temperature, and obviates the previous necessity for two-step thermal treatment. The proportion added is of the order of 0·03 to 0·3% calcium in a cast magnesium alloy containing 1–12% aluminium, 0·3–5% zinc, and 0·05–0·3% manganese.[11]

Molybdenum Alloys

Alloys of very high melting point which are suitable for X-ray targets and electrical contacts contain 60–99·75% molybdenum and 0·01–1% osmium, possibly together with copper, gold and other metals.[12] Powdered molybdenum and osmium are pressed to an ingot which is sintered (at 2,000° C. in a hydrogen atmosphere), forged and swaged. The resulting alloy can be used as a refractory base for alloys with copper, gold, etc.

Silver Alloys

The wear resistance of silver base alloys intended for electrical contacts is improved by quenching treatment, followed by ageing at a much lower temperature.[13] An alloy of silver with 10% copper was quenched from 750° C. and then aged at 250–300° C. Alloys with a high proportion

1 U.S.P. 2,185,987, Durion Co., Inc.
2 U.S.P. 2,185,464, H. A. Howell.
3 U.S.P. 2,186,758, D. E. Krause and Battelle Memorial Institute.
4 U.S.P. 2,188,138, Chapman Valve Manufacturing Co.
5 U.S.P. 2,185,596, New Haven Copper Co.
6 U.S.P. 2,185,809, Bridgeport Rolling Mills Co.
7 U.S.P. 2,186,116, Oxweld Acetylene Co.
8 U.S.P. 2,188,681, American Brass Co.
9 U.S.P. 2,185,348, W. E. Mansfield.
10 U.S.P. 2,188,203, W. E. Mansfield.
11 U.S.P. 2,185,452, Magnesium Development Corporation.
12 U.S.P. 2,188,405, P. R. Mallory and Co.
13 U.S.P. 2,187,377–378, P. R. Mallory and Co., Inc.

of palladium are quenched from above 600° C. and acquire a Brinell hardness exceeding 300 after ageing. Such an alloy may contain 40% silver, 42% palladium, and 18% copper. Another example with a much lower palladium content is composed of 67% silver, 23% palladium, 5% copper, 2% gold, and 3% tin.

While nickel itself is only soluble in silver to a minute extent, the presence of magnesium increases its solubility to a marked extent. The resulting silver-nickel-magnesium alloys are notable for their ductility in combination with high-tensile strength. Suitable proportions are 1–4% magnesium and 0·25–5% nickel.[14] Alloys with a much higher nickel content can also be made, preferably by sintering and not by melting. These alloys are indicated in the manufacture of electrical contacts, industrial apparatus and table silverware.

14 U.S.P. 2,187,379, P. R. Mallory and Co., Inc.

Columbium-Tantalum Alloys

An iron-containing class of alloy with a high rare metal content is made with the aid of oxides derived from ores of columbium, tantalum and yttrium.[15] These are fused in an electric furnace to yield an alloy containing, by way of example, 55% columbium + tantalum, 15% yttrium, 4% molybdenum, 20% zirconium, and the balance iron. Oxides of columbium and tantalum are derived from columbite, yttrium oxide from gadolinite. Yttrium is presumed to function as an oxidiser hardener during the alloying process. These alloys are proposed for the manufacture of cutting tools for work requiring high chemical resistance and heat-stability (up to 1,000° C.). They may also find application as surgical instruments, pistons, cylinders, etc.

15 U.S.P. 2,187,630, C. J. Schafer.

Fundamental Effects of Molybdenum in Steel

MOLYBDENUM additions to steel contribute markedly to deep hardening. In this respect it is considered to be second only to carbon. Consequently, in sections where deep hardening is a controlling factor, molybdenum raises the endurance limit (fatigue strength) of steel and enhances other properties controlled by depth hardness. It also raises the strength of steel at elevated temperature, and improves resistance to creep; further, it virtually eliminates temper brittleness when it is present in adequate amounts. The machinability of quenched and tempered steel at hardnesses above approximately 300 Brinell is improved by molybdenum. Closely paralleling its effect on elevated temperature strength and its ability to promote hardness, molybdenum permits the use of relatively high tempering temperatures to obtain a given hardness. The high tempering temperature contributes to the development of outstanding toughness at a given hardness. The corrosion resistance of stainless steels in certain applications is improved by molybdenum.

These factors are frequently encountered and are of considerable significance to the metallurgist and to the engineer, and a book recently issued,* which is concerned solely with the fundamental effects of molybdenum in steel, and the greater part of which is devoted to a consideration of the above factors. The effects of molybdenum on the tensile properties of steel, on hardness, fatigue, impact strength, elevated temperature strength, wear resistance, and corrosion resistance, are all briefly discussed in the light of research and experience, and considerable attention is given to fabrication and heat-treatment of molybdenum steels.

Molybdenum additions to steel do not promote the formation of tightly-adhering scale. On the contrary, most molybdenum steels are free scaling during the forging operation; consequently, forgings have good surfaces, die life is prolonged and pickling costs are reduced. The forging procedure does not differ materially from practice employed in the case of other alloy steels.

The effects of this element that are concerned with heat-treatment processes can be briefly summarised as follows:

1. Upper critical point is raised slightly on heating, and lowered on cooling.
2. Since molybdenum carbides go into solution relatively slowly, the required time at quenching and normalising temperatures is somewhat increased.
3. Transformation rate of austenite may be modified to an important degree.
4. Molybdenum steels soften less at the relatively high tempering temperatures required to relieve casting, forging, and quenching strains than steels containing molybdenum.
5. The addition of sufficient molybdenum to otherwise temper brittle steels will practically eliminate this undesirable phenomenon.

Considerable attention is given to the fundamentals of heat-treatment and to the effects on the transformation characteristics when molybdenum is added to plain carbon and alloy steels in progressively higher percentages. Reference is made to the so-called "S" curve as a convenient method for studying the transformation of steels on cooling from above the critical range, and "S" curves are given for some plain carbon and molybdenum steels.

Molybdenum imparts a stability of structure to quenched steels that requires a relatively high tempering temperature to produce softening. It is also known that internal stresses have a profound effect on the toughness of steel as measured by the Izod and Charpy impact tests. Tempering tends to relieve the internal stress, and the higher the tempering temperature, the more complete the relief. The relatively high tempering temperatures necessary for molybdenum steels result in high impact strength at high hardness and tensile strength.

Resistance to softening of molybdenum steels persists even in the presence of other alloying elements such as chromium.

Brief reference is made to case-hardening and nitriding; machining welding; flame hardening; and the effect of molybdenum in steel on these operations. The book contains much useful information on the subject.

* "Molybdenum: Fundamental Effects in Steel." Published by Climax Molybdenum Company, New York, U.S.A. Copies may be obtained from Climax Molybdenum Co. of Europe, Ltd., 2-3, Crosby Square, London, E.C.3.

Soldering of Aluminium to Nickel or Monel

IN order to secure improved adhesion, some investigators have electroplated aluminium, prior to soldering, with copper, nickel or iron. According to Ballay,[1] lap joints (1·2 in. overlap) in nickel-plated aluminium, 0·059 in. thick and ¾ in. wide, broke outside the joint at 660 lb. in tensile tests, and could be bent 90° at the joint without peeling.

In soldering aluminium to nickel, the nickel may be tinned before soldering. Holler[2] reports that an aluminium-nickel butt joint so made in nickel, 0·20 in. thick, showed a tensile strength of 11,400 lb. per sq. in. (5·1 tons per sq. in.). Similar joints in Monel, 0·20 in. thick, had a tensile strength of 4,700—6,400 lb. per sq. in. (2·1—2·86 tons per sq. in.). The low strength, as compared with that of the aluminium-nickel joint, was attributed to the formation of a brittle copper-rich layer adjacent to the Monel side. In butt joints in sheet, 0·039 in. thick, made more rapidly, the copper-rich layer was absent, and the tensile strength rose to 11,400—14,200 lb. per sq. in. (5·1—6·35 tons per sq. in.).

1 *Rev. Aluminium*, 1934, Vol. 11, Pp. 2365–70.

2 *Der Leichtmetall-Schweisser*: C. Marhold, Verlag, 1936

Oxy-Acetylene Welding of Stainless Steels

By L. Sanderson

Most manufacturers produce a welding quality of stainless steel developed with a view to facilitating good welding. In order to retain the stainless properties at the weld and effect a serviceable junction between the parts welded many important factors are involved, and in this article particular attention is directed to oxy-acetylene welding.

THE growing employment of stainless steels in aircraft, and particularly in the modern seaplane, has necessarily involved a considerable use of welding, and even though riveting may be necessary in certain instances, the invention of stainless steels of types not demanding heat-treatment after the welding operation has considerably extended possibilities in this direction. The oxy-acetylene welding of the stainless steels deserves more attention than has always been paid to it, and in this present article some notes on its use and scope will be given.

The oxy-acetylene process is quite suitable for welding these steels, and there is no special difficulty attached to its use, but it must be borne in mind that the technique is different from that employed in the welding of the standard mild steels. In the first place, undue heating of the weld must be avoided, as this will cause the steel to melt and bubbles of gas will be liberated. These will, in all probability, produce porosity in the weld metal and lead to failure. Secondly, the proportions of oxygen and acetylene in the blowpipe must be carefully controlled, or flaws in the weld will be certain. If, for example, there is too much oxygen, this will combine with other elements present to form oxide inclusions incapable of dissolution, and serving as possible focal points for the attack of corrosion. If, on the other hand, the acetylene is disproportionate, the weld metal will suffer from an excess of carbon which will cause the metal of the weld itself to lose ductility and become too hard, as well as become more liable to corrosion.

The actual welding procedure is a function mainly of the thickness of the steel being welded. Sheets not more than 16-gauge are usually flange-welded—i.e., they are provided with a flange roughly $\frac{1}{16}$ in. along those edges to be welded. These flanges are then painted with a flux. As soon as the blowpipe flame strikes the sheets to be dealt with, it melts these flanges first.

Another method is to place the joint on a supporting strip of metal possessing a high thermal conductivity, such as copper, but care must be taken not to liquefy this supporting piece, or it will pass into the metal of the weld and harmfully affect its composition and properties.

The welding rods employed should be of the same analysis as the material being welded. The flux should be made into a reasonably uniform paste by means of water. If these minor details are observed, it is quite feasible to produce a highly satisfactory weld on sheets between $\frac{1}{16}$ in. and $\frac{1}{8}$ in. without any special mechanical treatment of the sheet edges—e.g., bevelling off. Application of the flux must be on both upper and lower surfaces in order to prevent oxidation of the steel on the lower surface. Fluxing the lower surface produces a layer of slag which shuts out any gases likely to produce harmful oxidation. A valuable hint is to incline the seam of the weld a trifle in order to send the melting flux running down the slope in advance of the heated area. This is particularly advisable for the lower surface and brings about a bright welded line of smooth surface.

For sheets above $\frac{1}{8}$ in. thick the welding edges must be bevelled off and painted with flux. The underside of the weld seam must also be painted.

A point often overlooked is the direction of the welding. If the plates are over $\frac{1}{8}$ in. in thickness, they must be welded from left to right, but thinner sheets should be welded from right to left. The more swiftly the welding is executed the better, so long as proper care is observed, and only one side should be dealt with. Otherwise, it will be essential to heat-treat the steel first at a rather high temperature, and this is often troublesome. Another point is to eschew puddling of the welding rod, which causes porosity in the weld and reduces the physical strength.

The developing use of stainless steel castings makes their welding by the oxy-acetylene process equally useful, but in this instance a pre-heat-treatment with a later slow cooling is advisable, while if definite mechanical properties are required, it may be necessary to heat-treat after welding also. Here, again, the welding rods must be identical with the steel to be welded, but a little extra acetylene should be introduced if the castings have over 0·5% carbon.

The flame used should show only a slight feather of acetylene, though this rule must be interpreted in the light of the casting's type. For example, a carbon content of from 0·5 to 1·95% demands only a slight feather, but castings containing between 2·0 and 3·0% carbon require a broader feather. In any event, however, the length of the feather must never be greater than that of the inner cone.

If the castings contain chromium, as is almost inevitable in stainless steels, a special flux will be essential, and the maker of the stainless steel shou'd be asked for his precise recommendations. In welding chromium steel, oxides of iron and chromium are produced which, if neglected, will occasion weld failure or weakness. The use of a flux causes these oxides to pass into solution, and simultaneously produces a slag which melts at the welding temperature. The oxides, impurities, dirt, and other foreign or undesired particles, are thus able to make their way upwards through this until they float as a scum on its surface, where they can be skimmed off. It should be stressed that thorough cleansing of all the surfaces to be welded should be carried out before the actual job. Take care also to give the job support, so that its own weight will not pull apart the freshly welded surfaces.

It will be appreciated that the high welding temperatures essential set up stresses in the steel as soon as it begins to cool down, and if something is not done to ease these, damage may be caused. The stainless steels, rich in chromium as they are, are of intricate grain pattern, while their physical properties are diverse. Haphazard methods cannot, therefore, produce a strong and ductile weld metal. The operator should be familiar from the start with the type, structure and analysis of the material he is to weld, the heat-treatment it needs to put it into the proper condition, and the precautions essential in welding it. This necessitates an outline of the different classes of stainless and heat-resisting steels from this point of view.

The stainless chromium irons come first, though to-day these are not so widely used in the manufacture of aircraft as at one time seemed possible. They contain 11–14% of chromium with 0·12% carbon or under. They will harden

in air from 775°–800° C., and when welded the area in the neighbourhood of the weld becomes hard and brittle. Obviously, the steel must not be left in this condition, and a form of heat-treatment designed to improve the grain structure becomes necessary. The metal is heated to 670°–750° C. for 30 mins., then cooled off in the furnace or in still air. If the weld is of small dimensions and confined to one place furnace treatment may not be essential, and, indeed, there may be no furnace available. The blowpipe flame can then be used to soften and toughen the affected area, though this practice is by no means to be recommended, and furnace treatment is always preferable. The steel should never be heated to beyond 775° C. (dull cherry), nor should it be maintained at that temperature for more than 5 mins.

In oxy-acetylene welding of the stainless irons, excess oxygen must be avoided at all costs, as it causes porosity due to the liberation of gas bubbles. A trifle too much acetylene will not do any serious harm, but a real excess will create carbonization of the weld metal and impair its resistance to corrosion. The flame must be carefully regulated so that it becomes of barely reducing character, and the valves should then be turned back until the acetylene feather has virtually disappeared.

The straight chromium steels, as distinct from the irons, are higher in carbon, and contain 12–16·0% chromium with 0·2% or more carbon. They are used for engine valves, spindles, propeller shafts, and many other parts, while their use in aircraft is rapidly increasing. These steels, if allowed to cool down from a high heat in still air, become very hard, and welding thus sets up a condition of extreme hardness and brittleness in the neighbourhood of the weld. This condition has to be eliminated by an annealing treatment which comprises heating up to 815° C. and then allowing to cool down slowly in a closed furnace or in a box buried in ashes or lime. One effect of this treatment is a diminution of corrosion-resistance, but a hardening and tempering treatment will restore this. The surface of the welded part must, however, be well finished, so as to provide the best possible degree of resistance to corrosion.

It must be pointed out in connection with these steels that they are not suitable for welding where the welded piece will be called upon to withstand severe vibration or stress, unless they have been given an intricate and careful heat-treatment demanding costly plant, or unless it is feasible to place the stresses upon some other part more capable of bearing them.

We now come to the ferritic stainless steels, which have a chromium content higher than that of the stainless irons, but in addition contain a percentage of silicon (0·5–1·5%). The chromium percentages range from 17–19. More resistant to corrosion than the irons, they do not harden when cooled down, while their silicon addition makes them easier to weld. Against this, however, is the fact that the high temperatures of welding create coarsening of the grain and consequently brittleness in the welded zone. Since this cannot, in these steels, always be cured by heat-treatment after the operation, the remedy is to employ a welding rod of austenitic nickel chromium 18–8 stainless steel. This produces a strong and ductile weld. Not even this, however, will entirely eliminate the tendency to brittleness, but the welder can do a great deal to reduce this brittleness to a minimum by his own personal skill. A heat-treatment that has been found beneficial in certain instances is to anneal in the furnace at 650°–750° C. and then allow the part to cool down in still air.

The heat-resisting chromium alloys, which are mainly designed for engine use in valves, exhaust manifolds, etc., are highly corrosion resistant, but are by no means readily welded because their high chromium content makes them brittle. Furthermore, sharp changes of temperature lead to severe stresses, and their lack of brittleness makes it difficult for them to resist these. They remain fairly ductile so long as the temperature is below 475° C., but a prolongation of the heating, or a slow cooling from 550°–400° C. makes them extremely brittle, and this brittleness can only be eliminated by reheating to bright red followed by rapid cooling. If the piece to be welded is of rather large section, it is best to preheat the entire part to 475° C. and weld complete at one go, to avoid local reheating. The reheating must be above 475° C. if the weld and its neighbouring zones is to remain ductile or resume ductility.

The most valuable group of stainless steels is, as is well known, the austenitic 18–8 nickel-chromium stainless steels, containing from 17–25% chromium and 7–12% nickel, plus other elements added for specific purposes. These steels do not become brittle when welded, and do not harden in air, so that the speed of cooling does not influence the ductility of the metal. They are thus well suited to the welding operation. A carbon content of below 0·12 and the possibility of acute corrosive attack alone render a heat-treatment advisable, and this consists of raising them to a temperature of 1,000°–1,040° C.

No flux is necessary, though for the satisfactory bottom fusion of the steel, a flux is desirable. The physical characteristics of the weld metal will depend on the type and properties of the steel in advance of welding. A thin, moderately cold-worked sheet will give a stronger weld than a fully softened steel. A moderate amount of cold work will also lessen the extent of carbide precipitation in the course of welding.

Water-quenching from the welding temperature is inadvisable, because it softens the steel, creates dangerous stresses, and produces distortion. Air-cooling produces sufficient ductility in the weld. Weld-decay must be avoided. Most of the standard types of austenitic stainless steel need a heat-treatment after welding, but sometimes the piece is too big for heat-treatment, or the proper plant is not at hand. For this reason metallurgists have developed types of austenitic stainless steels not requiring heat-treatment after welding. Their method is to add alloys, such as titanium, columbium, or molybdenum, or perhaps two of these, or all three together. These stabilise the structure of the steel in the welded zone, and so prevent both intergranular corrosion or "weld-decay" and the creation of dangerous stresses.

The austenitic stainless steels expand much more when heated than do low carbon steels, and are only poor conductors of heat as compared with the low carbon steels. If the piece or sheet to be welded is thin, therefore, there is a considerable danger of distortion, which should be eliminated by a suitable heat-treatment and the use of jigs and chill plates.

To sum up, in oxy-acetylene welding of austenitic stainless steels, too much acetylene or oxygen in the flame must be prevented, or the result will be carbon absorption or porosity. A too reducing flame produces a weak and brittle weld. Cleaning the work before welding is essential. Wherever possible, use a stainless steel developed specifically for welding, and obtain this fully softened and descaled. Use sheet rather than strip. Fully soften and descale the welds after the operation if it has not been possible to use a type of steel not requiring heat-treatment after welding. In welding sheets, use a wire gauge as heavy as or a trifle heavier than that of the sheet to be welded. The gap between the sheets must be one-half the thickness of the sheets.

If descaled stainless steel sheets cannot be used for welding purposes, clean the parts to be welded and in the neighbourhood of the ultimate weld by scrubbing with a wire brush, by grinding if the edges have been bevelled, or by washing with the same mixture as is employed for descaling.

THE *Nickel Bulletin* for November includes abstracts dealing with current work on nickel catalysts in hydrogenation processes, methods of producing perfect electrodeposited coatings, effects of hydrogen in steel, flame cutting of alloy steels, selection of steel for gears, and the magnetic permeability of austenitic nickel-chromium steels.

Copies may be obtained free of charge on application to the Bureau of Information on Nickel, Grosvenor House, Park Lane, London, W. 1.

Recent Heat Treatment Furnace Installations

Contributions to those Refinements in Practice which Fulfil the Demand for Better Quality Products

Careful study of heat-treatment operations and the development of approved technique in recent years have enabled furnace makers to design and build furnaces for specific or general services capable of meeting the ever-increasing demand for better quality of the finished product. The progress made has been invaluable during this period of national emergency and has facilitated the fulfilment of heavy demands for new heat-treatment plant and equipment, since existing designs have been reproduced or only slightly modified to satisfy particular requirements. Some of these new installations are briefly reviewed.

ADVANCES made in recent years in the design and construction of heat-treatment furnaces are helping furnace makers considerably in meeting the heavy demand for new plant and equipment during this period of national emergency. There has been no time to concentrate on further developments of major importance, and furnaces installed during the period under review are either reproductions of existing designs or only slightly modified to meet particular requirements. But so great has been the progress in recent years that modern heat-treatment furnaces can be regarded as highly efficient precision tools capable of contributing those refinements in practice which assist in fulfilling the demand for better quality of the finished product.

Whether the treatment involves annealing, normalising, carburising, hardening, tempering, solution treatment or ageing, very efficient furnaces are available, and advances in the technique, developed for the material and components treated and associated with their operation, satisfactorily fulfils the requirements of the particular processes. Take the furnaces developed for normalising sheets, for instance; these are usually of the continuous type, and their essential characteristics are: (*a*) that the sheets should be carried through the furnace smoothly and without injury to the surface; (*b*) that the amount of fuel required for the operation should be a minimum; (*c*) that the surface of the sheets when normalised should be equal to a mill finish when loose rolled; (*d*) that the plant should be capable of working throughout the entire week without the necessity of closing down for cleaning purposes; (*e*) that rider sheets are unnecessary; and (*f*) that the sheets should be free from scale and blisters. A typical normalising furnace which fully meets all these requirements is shown in Fig. 1.

The general method of operation in this type of furnace is to carry the sheets horizontally from end to end of the furnace. Static and moving members extend through the heating and cooling zones from a point about 10 ft. in front of the charging end of the furnace to any required distance beyond the discharging end. Preheating, soaking and cooling chambers constitute the sequence of heat-treatment. The furnace is fired by clean gas on the "Wellman-Chantraine" principle, viz., the air for combustion is admitted to the furnace chamber through small holes arranged in the furnace crown; the clean gas is introduced through ports arranged just below the skew-backs of the furnace crown in the side walls of the combustion chamber.

The gas ports are designed to throw the gas in an upward direction to follow the contour of the crown. By this means the air for combustion is isolated from the surface of the sheets, which are entirely surrounded by the flame. The height of the furnace crown in the preheating zone is arranged so that the flame reaches well below the sheets, thus ensuring uniform treatment.

Washed producer gas, blast furnace or coke oven gases, have been found to be entirely satisfactory for the normalising of fine quality steel sheets, as they do not affect the sheet surface; they are also easily handled and controlled. An important feature of the furnace illustrated is the elimination of rider or carrier sheets which, apart from their cost and labour in handling them, waste a considerable amount of heat.

The sheets are conveyed through the furnace on a patent walking beam system. The beams move in an endless path, vertically upwards, horizontally forward, vertically downward, and horizontally rearward. This movement is progressive, and a sheet placed upon the stationary beams

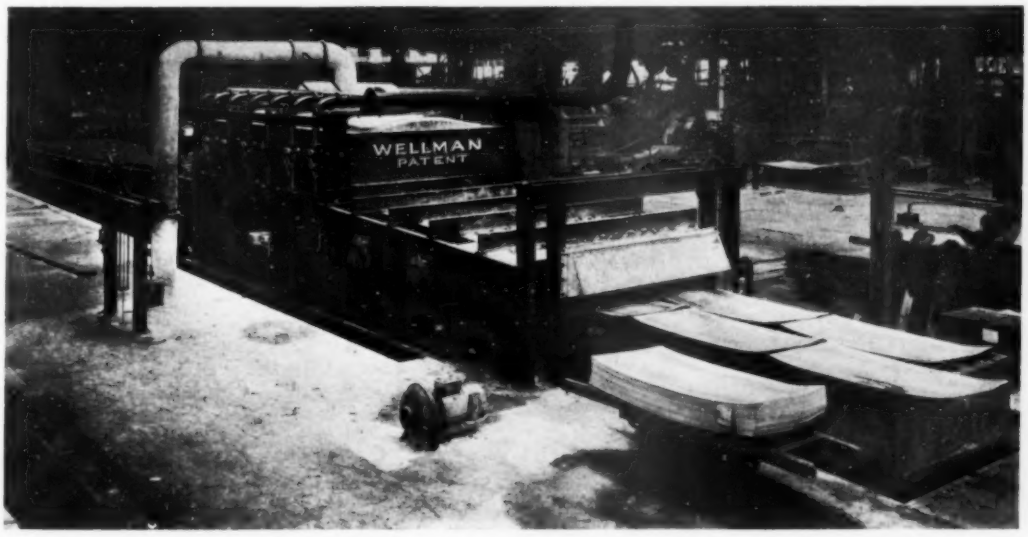
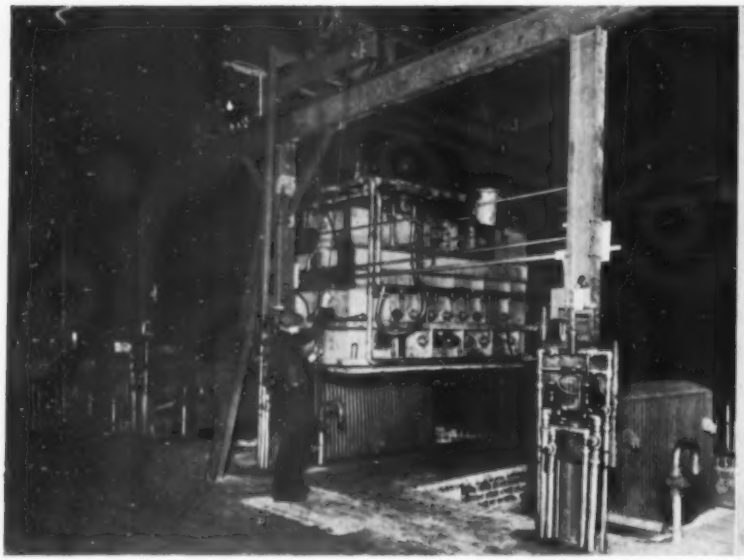


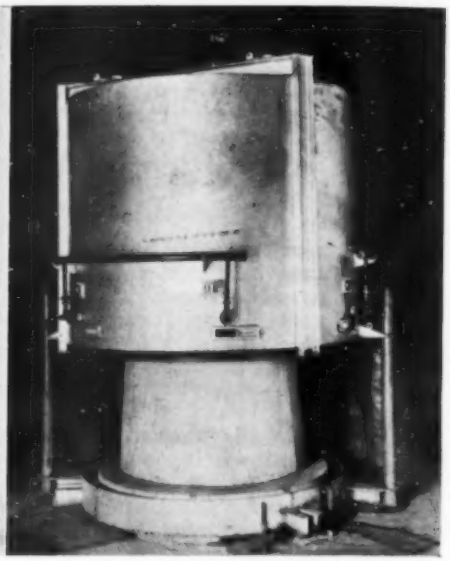
Fig. 1.—A continuous sheet normalising furnace.

Courtesy of Wellman Smith Owen Eng. Corporation, Ltd.



Courtesy of Birmingham Electric Furnaces, Ltd.

Fig. 2.—A bright annealing furnace comprising four hearths and one gas-fired furnace.



Courtesy of Incandescent Heat Co., Ltd.

Fig. 4.—Bright-annealing furnace for wire and strip in coil form.

is raised and moved forward horizontally and replaced upon the stationary members—thus the sheets are moved forward step by step. The small amount of sag that takes place between each supporting side member is reversed when the moving members take the weight of the sheet in between the static members. The practical effect of this is to make the sheet flat by the constant changing of the stresses in the sheet. It is noteworthy that even the thickest sheets, badly curved direct from the rolls, flatten out to a plane surface before leaving the hot zone of the furnace.

A complete system of temperature control is an important feature of this furnace, and every provision is made against excessive temperature fluctuations.

Atmosphere Control

In the realm of the bright annealing of metals and alloys progress in recent years has been most marked, and to-day a very wide range of furnaces are in use for diverse heat-treatment operations that employ some method of atmosphere control. The advantages of obtaining fully annealed metals in a perfectly bright condition are well known, and it is now recognised that the use of controlled atmospheres for the heat-treatment of semi-finished material or of components is of tremendous value to metal users, as it eliminates pickling and polishing operations with considerable reduction in cost of the finished products.

There is no lack of suitable materials for providing

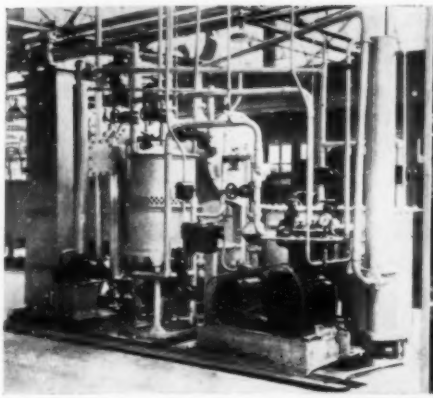
Fig. 3.—Electrically heated pit-type furnace for aero-engine parts.

Courtesy of Metalectric Furnaces, Ltd.

atmospheres that retain the bright surfaces of metals during annealing or which prevent the formation of scale, but much attention has been directed to the finding of the cheapest and most convenient material for each particular job. The main object is to eliminate oxygen from the furnace atmosphere, and for this purpose the controlled atmospheres used may conveniently be divided into two groups: those that contain carbonaceous gases and those which do not. Ferrous materials in particular are heat-treated in atmospheres derived from carbon compounds, of which many are suitable, but major importance is attached to butane, propane and coal gas. By the controlled combustion of these gases with air, an atmosphere may be produced which consists essentially of nitrogen, hydrogen, carbon monoxide, carbon dioxide and water vapour. Sulphur compounds are usually present in these gases and can be removed by suitable apparatus; the removal of the sulphur is particularly important in electric furnaces, as it attacks nickel-chromium heating elements. Coal gas is now more generally used, since it is reasonably cheap and easy of access.

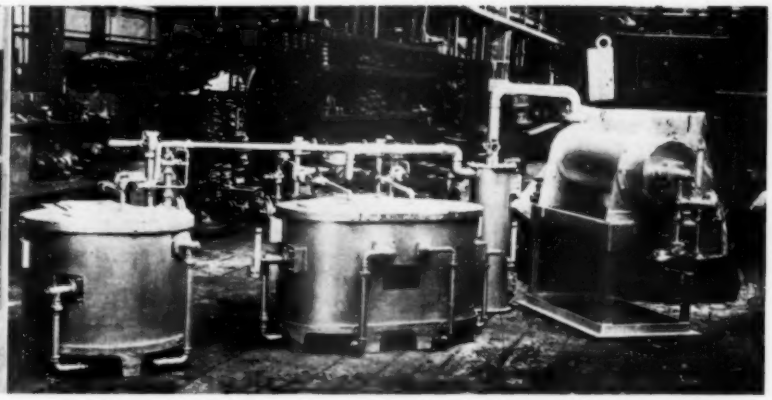
Those controlled atmospheres derived from sources not containing carbon compounds consist essentially of mixtures of nitrogen and hydrogen, although in the manufacture of magnesium and light alloy material and components such gases as chlorine and sulphur dioxide are used. The materials from which mixtures of nitrogen and hydrogen are obtained are more limited than with carbon compounds, but a convenient raw material is available in the form of anhydrous ammonia. It is extremely pure, and when compressed at normal temperatures to about 80 lbs. per sq. in. is a liquid. It is available in cylinders and is reasonably cheap. A small plant, such as the ammonia cracker developed by Imperial Chemical Industries (Fertiliser and Synthetics Products) Ltd., is necessary to dissociate the anhydrous ammonia into its constituent elements, hydrogen and nitrogen, for the production of the atmosphere.

By the controlled combustion of cracked ammonia with air, a gas results which consists essentially of nitrogen admixed with hydrogen. When complete combustion of the hydrogen of the cracked ammonia takes place, two volumes of ammonia, giving four volumes of cracked ammonia, produce seven volumes of nitrogen and three volumes of water vapour, which is condensed out. In ammonia burners it is customary to control the combustion so that the resulting gas mixture varies between 90 to 99% nitrogen, and 10 to 1% hydrogen. It is generally recognised



Courtesy of Incandescent Heat Co., Ltd.

Fig. 5.—Gas-conditioning unit for producing a protective atmosphere.



Courtesy of British Furnaces, Ltd.

Fig. 6.—An installation for the heat treatment of high-speed steel drills and reamers.

that nitrogen containing a small percentage of hydrogen provides an ideal atmosphere for most bright heat-treatments in both ferrous and non-ferrous metals, providing the mixture is free from water vapour and free oxygen.

The application of controlled atmospheres to heat-treatment operations has increased considerably since the outbreak of hostilities; they are applied to bright annealing, stress relieving and normalising; bright hardening and bright tempering; descaling of hot-rolled materials and of components; and bright brazing with copper and silver solders. Among the many recent installations of heat-treatment furnaces which incorporate atmosphere control is that shown in Fig. 2. It illustrates a bright-annealing furnace comprising four hearths and one gas-fired furnace. The hearths take a charge measuring 6 ft. by 2 ft by 2 ft. 6 in., and will accommodate two ton charges of bright steel coils. An artificial atmosphere is used in order to prevent oxidation and decarburisation during annealing. The hearths are fitted with bands designed to circulate air completely around the charge, thus accelerating heating and cooling and assisting in obtaining close temperature control. A movable heating chamber is lowered over any one of the hearths in order to heat the charge, and the average time of heating and soaking a full charge at the operating temperature of 650° to 750° C. is five hours.

The electrically heated pit-type furnace shown in Fig. 3 is a general purpose furnace, and is used for hardening or tempering and occasionally for carbonising. The furnace illustrated is used for the heat-treatment of aero-engine components at temperatures up to 1,000° C. The chamber dimensions are 16 in. in diameter and 14 in. deep. The heating chamber is fitted with a gas injector, which operates on low-pressure town gas, to provide a non-oxidising atmosphere when required. A fan is fitted in the hearth to ensure maximum uniformity of temperature up to 650° C.; beyond this temperature it is not used.

The furnace shown in Fig. 4 has been specially developed for the bright annealing of wire and strip in coil form. Installations of this type usually consist of three or four bases, with inner covers and purging gas shields, to one outer cover. This permits continuous operation, as the load on one base can be under treatment while the other bases are used for cooling, unloading and reloading purposes. The charge is supported on a perforated plate and is covered by a light inner cover which fits into a sand seal around the base. This cover is of mild steel, aluminised on the outside, and provided with a skirt which dips into a water trough, providing an additional seal. The outer cover or heating chamber is equipped with special ring burners, and the combustion system is connected to the gas main supply by means of a flexible tube. Each base is fitted with a fan, which materially assists during the heating and cooling cycle.

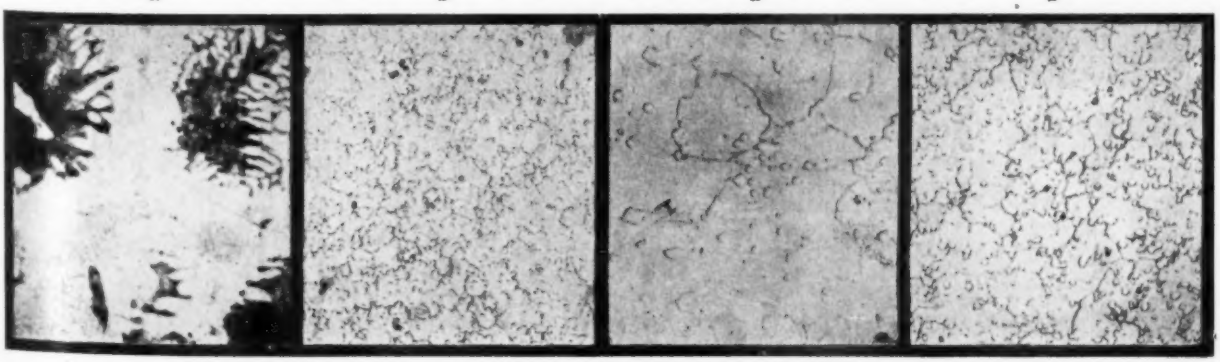
Throughout the heating and cooling cycles the inner cover is purged with conditioned gas, the use of which ensures perfect bright annealing of the charge. This protective atmosphere is supplied from a separate gas conditioning unit in which town gas is partially burned, dehydrated and desulphurised before being introduced inside the inner chamber. The amount of conditioned gas produced in the separate unit, which is shown in Fig. 5, is between three and four times the amount of town gas used.

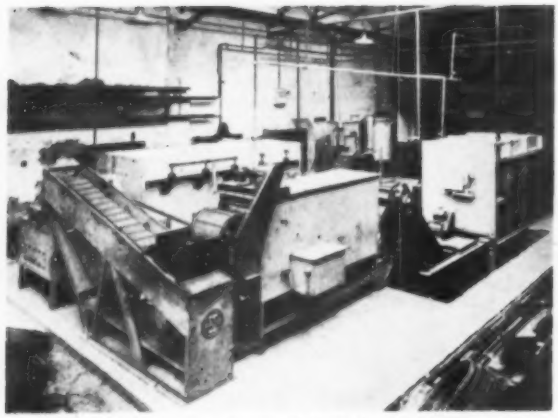
The high temperatures required for the successful heat-treatment of many alloy steels have greatly increased the difficulties associated with heating operations. This is especially true of high-speed steels, the heating of which was studied by the research department of the Sheffield Gas Company some time ago. As a result of this work a

Fig. 7.—Micrographs of the same steel treated in (a) open type furnace, and (b) atmosphere controlled furnace.

Heated at 1,320° C. for 15 mins. × 600 **Heated at 1,300° C. for 15 mins. × 600**

a **b** **a** **b**





Courtesy of Birmingham Electric Furnaces, Ltd.

Fig. 8.—An installation for the continuous scale-free hardening and tempering of bolts.

controlled atmosphere process was developed which has proved very successful in practice. Furnaces incorporating the patented process have been designed and built for the heat-treatment of all forms of tools, including milling cutters, reamers and twist drills.

The purpose of the process is to eliminate the formation of scale and to prevent decarburisation at the same time. Since it has been put into practical operation, one feature has been recognised as having added considerable value to its adoption: tools so treated have a longer cutting life than tools made from similar steel treated under ordinary furnace conditions. Cutting tests on high-speed steel reamers, twist drills and hobs have shown 100 to 150% increase in life over similar tools treated by ordinary methods.

An installation for heat-treating high-speed steel twist drills and reamers, incorporating this process, is shown in Fig. 6. It consists of a double chamber pit type preheat furnace in the centre with a single chamber high temperature furnace on the left. On the extreme right is the unit for producing the special atmosphere used in the muffles of both furnaces. Town gas is burned in the unit at a fixed rate and under definite conditions to produce products of combustion of known composition, and these flow through a vertical water-cooled vessel where they are reduced to a temperature sufficient to lower the water vapour content appreciably.

The mixture of gases which leave the cooler consist almost entirely of carbon dioxide and nitrogen. The latter is without effect on steel, but the carbon dioxide, in the presence of a small amount of water vapour, is capable both of scale formation and decarburisation, but to a less marked degree than either water vapour or air. To overcome even this slight tendency to affect the surface and carbon content of the steel, a small amount of unburned town gas is added to the mixture, leaving the cooler in such a way that efficient mixing takes place.

When this mixture of gases passes into the working chamber, its temperature rises, and reactions take place which alter its composition, the composition of which depends upon the temperature of the furnace when using any one ratio of cooled burned gas and unburned gas. This ratio is under definite and simple control and allows any desired type of atmosphere to be produced in the furnace. These atmospheres are not to be confused with those referred to as oxidising, reducing or neutral; they are more correctly referred to as "balanced atmospheres" adjusted by a consideration of the composition of the steel being heated and the temperature of the operation.

The results obtained with any class of steel which requires to be heated to any temperature up to 1,385° C. are perfectly consistent, and it can be guaranteed that no decarburisation takes place and that there will be no more than 0·0001 in. of scale. In addition, it is possible to control the internal structure or grain growth. The illustrations in Fig. 7 show the internal structure obtained by heating high-speed steel under different furnace conditions. The steel is the same in each case, the standard 18–4–1 type, containing 18% tungstun, 4% chromium, 1% vanadium, and 0·7% carbon. Steel specimens of the same weight and shape were used in each treatment. Some were heated in an ordinary open type furnace of modern design and others in the controlled atmosphere furnace developed and patented by the Sheffield Gas Company, and built under licence by British Furnaces Ltd.

Another interesting installation in this category is that for the continuous scale-free hardening and tempering of bolts, shown in Fig. 8. It comprises a gas-heated, direct-fired continuous cast link conveyer furnace arranged for use with a controlled atmosphere, a gas plant, a quench tank for the hardening furnace, a continuous belt-conveyer tempering furnace similar to hardening furnace, a quench tank, washing and degreasing plant, and a gas plant to supply a non-scaling atmosphere. The hardening furnace is arranged for use with a controlled atmosphere at temperatures up to 850° C., and the tempering furnace up to 700° C.

Fig. 10.—A box type furnace for the heat-treatment of light alloys.

Courtesy of Metalectric Furnaces, Ltd.

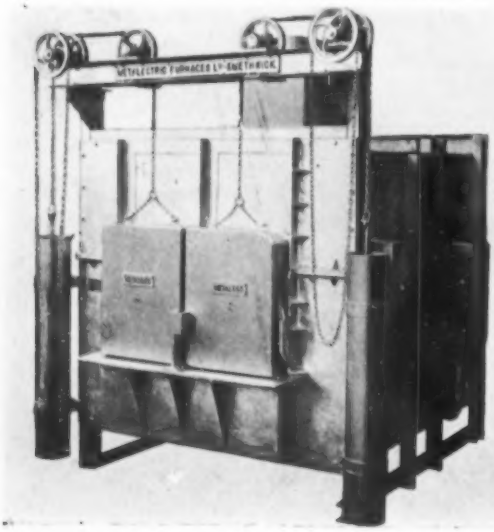
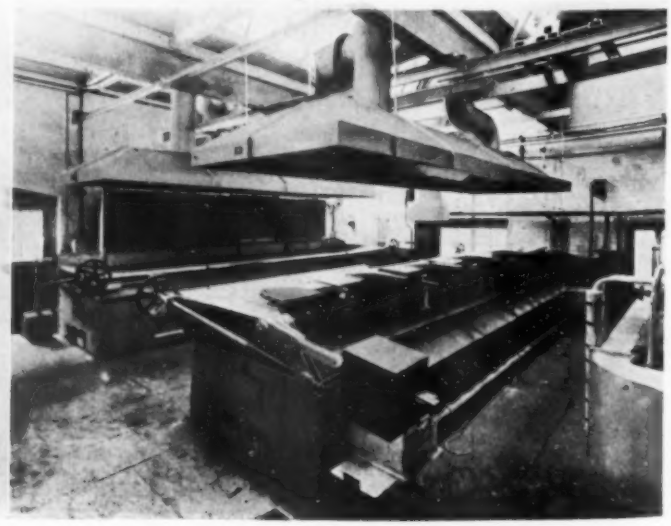
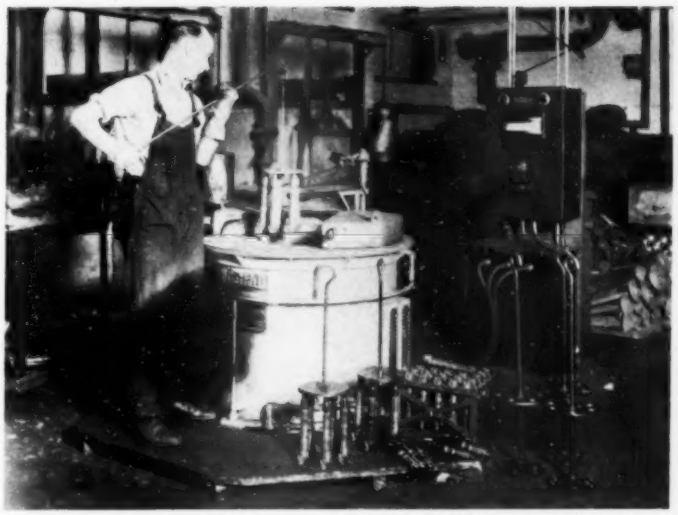


Fig. 11.—Large salt baths for the treatment of aluminium alloy parts.

Courtesy of Incandescent Heat Co., Ltd.



The vertical furnace shown in Fig. 9 is installed at the works of a leading automobile manufacturer; it is used for general hardening of automobile parts which are generally carried upon a jig, as shown, and suspended in the furnace chamber from the tool post. This furnace has a work chamber 16 in. dia. and 28 in. deep, and is rated at 18 kw. It incorporates the Wild-Barfield heavy hairpin heating elements fed from a step-down transformer. Fully automatic control is employed, and use is made of this firm's counterscale curtain equipment to prevent scaling and decarburisation. The flow meters for this latter unit are visible on the right side of the furnace.



Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 9.—Vertical furnace for general hardening of automobile parts.

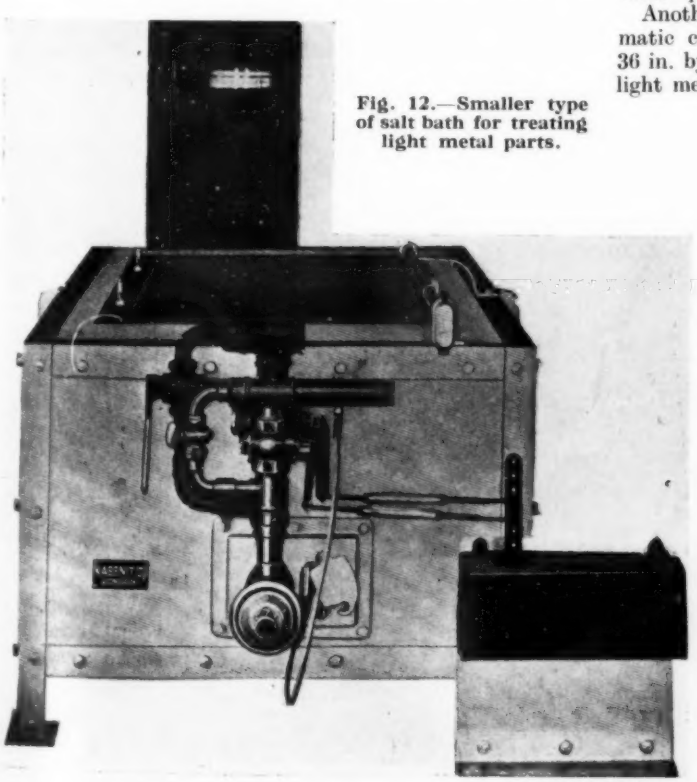
Low Temperature Treatment Furnaces

Advances made in low temperature treatments have been of great value, especially in the treatment of the light alloys. For these treatments furnaces require precise operation within narrow limits of temperature, and in electric furnaces developed for this purpose the heat is transferred by convection currents, but radiation is slow, and in order to obtain rapid transference of the heat a turbulent atmosphere is promoted by forced air circulation. To accomplish this one or more fans operate in the furnace chamber, the number depending upon the type and size of the furnace. A furnace of this type is shown in Fig. 10. It is suitable for temperatures up to 600° C., and the fan which effects even distribution of the heat is located in the roof.

In addition to forced air circulation furnaces, salt baths have also found favour for these low temperature treatments. They are more rapid heating than fan furnaces, and since the bath can be maintained at a uniform temperature, the heating of light metal components can be controlled within very narrow limits. Two large salt baths of this type, designed for the treatment of aluminium alloy fabricated parts, is shown in Fig. 11. Each unit is 15 ft. 6 in. long, 2 ft. wide, and 2 ft. 3 in. deep. Firing is by means of a series of incandescent natural draught burners fitted to each side of the bath, and at short distances apart, equalising the heat delivery to the bath and making it constant throughout the length.

Firing is mainly indirect, complete combustion of the gases taking place behind brick walls dividing the combustion chambers from the sides of the tanks, thus avoiding flame impingement. The burners are so placed that heat delivery to the bath takes place near the top, live heat being delivered to the point where the greatest amount of chilling takes place when the components are immersed, and also where heat loss to the atmosphere has to be compensated. This method also has the advantage of melting the bath from the top downwards, precluding the possibility of explosions due to excessive pressures being built up within the frozen salt.

Another salt bath furnace which is equipped for automatic control is shown in Fig. 12. Its dimensions are 36 in. by 24 in. and 12 in. deep, and it is used for smaller light metal parts. Many different forms of salt baths are

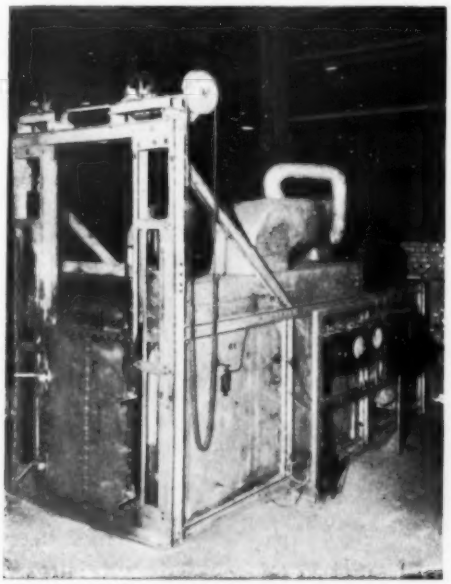


Courtesy of Kasenit, Ltd.

Fig. 12.—Smaller type of salt bath for treating light metal parts.

Fig. 14.—Gas-fired diffused circulation type heat treatment oven for magnesium alloy castings.

Courtesy of Controlled Heat and Air, Ltd.



Courtesy of Controlled Heat and Air, Ltd.

Fig. 15.—General view of a complete light alloy ageing plant.

in general use, and in addition to affording effective atmospheric control, they provide surface protection when the parts are removed from the bath, and are especially useful for aircraft parts, which depend upon uniform heating to an accurate temperature and subsequent quenching for their best properties.

Users of salt bath furnaces find it necessary to make frequent clearance and changes of salt as the most effective means of maintaining the ideal chemical balance; freedom from contamination and corrosion of work; and increasing the life of the pot or container. To facilitate the discharge of salt baths a salt ejector has been developed by The Incandescent Heat Co., Ltd., which enables the adoption of weekly or monthly cleaning out and inspection cycles with the ease and simplicity of the average plant maintenance task. This automatic salt ejector has completely emptied a 15-ton capacity salt bath in about twenty minutes. The arrangement of the ejector is simple, and the unit will operate on baths of all capacities, and its proportions may be arranged to suit the design of any furnace unit.

The battery of vertical furnaces shown in Fig. 13 were especially designed for the heat-treatment of light-alloy castings and forgings; they employ forced-air circulation of the directional type. The work-baskets which can be seen at the back of the illustration are 72 in. diameter and 106 in. deep; on account of their size, they are provided with three side-hinged doors to facilitate charging and discharging. The rating of each furnace is 120 kw. In each of these furnaces the centrifugal fan is mounted in the roof. The door is naturally heavy and considerably larger than would have been necessary with a bottom fan and special attention had to be paid to the operating mechanism. The vertical motion of the doors is effected by means of the hand-wheels shown: this rotates the screwed shaft operating in turn toggle arms. For traversing the drive is communicated from the second hand-wheel to the bogie-wheels via chain and sprockets. The control gear comprises a single-point indicating controller with a separate three-point recorder all of potentiometric pattern. It is noteworthy that a variable thermal protective device is provided with each furnace to prevent damage to either furnace or charge in the event of failure of the automatic temperature controller.

Diffused Circulation Heating System

In the solution treatment and ageing of magnesium alloy components controllable atmosphere furnaces are frequently used, in which combustion takes place in an external combustion chamber, the products of combustion being circulated by means of a fan and returned. The recirculation of combustion products makes the control of the atmosphere composition a simple matter, increases the efficiency of the furnace, and gives a lower combustion chamber temperature. A gas-fired diffused circulation furnace of this type is shown in Fig. 14, while Fig. 15 gives a general view of a complete light alloy ageing plant. This installation comprises two batteries of three batch type and two pit-type ovens. All these ovens are heated by the diffused circulation systems, the main feature of which is uniform temperature under any condition of loading.

Special Purpose Furnaces

Many special purpose heat-treatment furnaces have recently been installed, and Fig. 16 shows one of these in course of construction. It is a duplex nitriding furnace. It is well known that in the nitriding process the essential considerations are accurate temperature control, uniformity of heat distribution and the exclusion of air from the work containers during both heating and cooling. The type of furnace illustrated was designed to avoid difficulty in removing the container from the furnace while hot and to save the time which is wasted where it is necessary to cool off the furnace and container together. Two containers are located on stationary hearths, and the heating

Fig. 13.—A battery of vertical furnaces for the treatment of light alloy castings and forgings.

Courtesy of Wild-Barfield Electric Furnaces, Ltd.

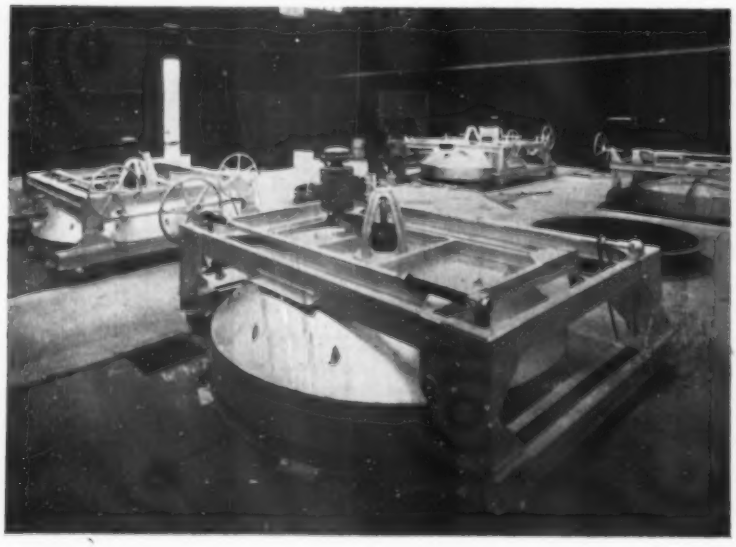
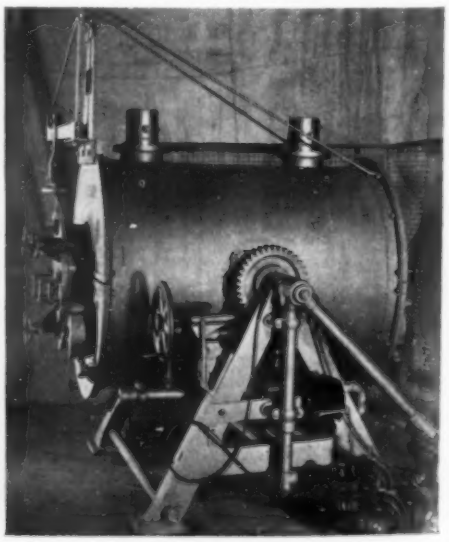


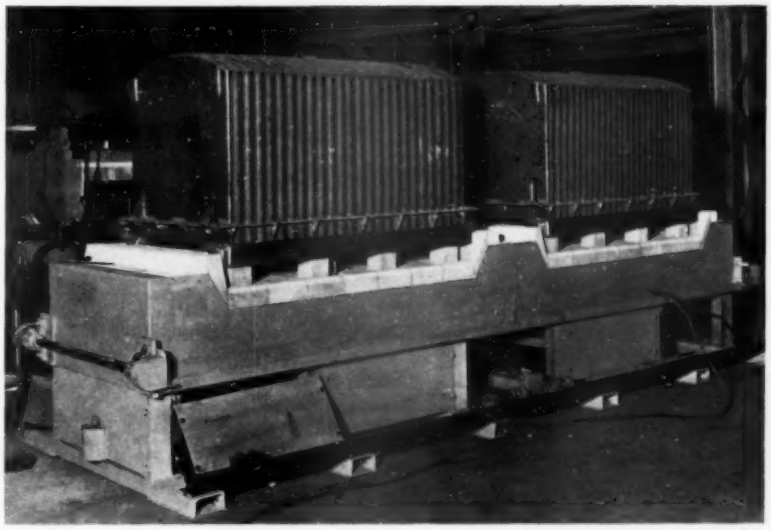
Fig. 17.—A gas-heated rotary furnace for carburising small repetition parts.

Courtesy of Brayshaw Furnaces and Tools, Ltd.



chamber is mounted on track wheels so that it can be located over either container. By means of a circulating fan very accurate temperature distribution is ensured, and the intimate contact of the ammonia secured permits full loading of the containers without risk of uneven treatment

The gas-heated rotary furnace shown in Fig. 17 has been specially designed for carburising small repetition parts. The rotating drum is of nickel-chrome heat-resisting steel. The furnace can be tilted for charging and discharging by means of a hand wheel, and the front cover is clamped in position. When it is necessary to charge or discharge the furnace a small gantry facilitates the handling of the cover. This furnace is heated by gas and air pressure burners under accurate control, and it is equipped with automatic temperature control.



Courtesy of Birmingham Electric Furnaces, Ltd

Fig. 16.—A duplex nitriding furnace in course of construction.

Reviews of Current Literature

A Practical Welding Course

WITH the rapid application of welding processes to the various engineering industries, the demand for trained welders increased and for a time there were insufficient to meet the demand, and it was necessary to provide facilities for adequate training. This question of training has been given considerable attention during recent years, and the success achieved has contributed in some measure to the expansion of welding processes. Increased demands necessitated by the war, however, are straining these training facilities, and this book is designed to accelerate training in the shop. The object of the author is fourfold : It is to assist the student to a clear and practical understanding of all the factors involved in the arc welding of metals ; to provide the instructor with a useful source of reference and a practical handbook to implement his teaching ; to widen the knowledge of the experienced welder in respect of the many factors which are not directly concerned with actual welding practice, but have an important bearing on the results obtained ; and to assist the executive who is responsible for the work of a welding shop.

The text matter in the book has been subdivided into thirteen chapters, which cover practically every phase of arc welding in a logical sequence to present a complete and practical course of instruction. A review of methods is followed by a brief discussion of the fundamental electrical principles involved, and on the types of equipment which are available. The metallurgy of steel and cast iron is briefly discussed, and three chapters are devoted to various aspects of welding practice and a special section on cast-iron welding. Two chapters deal respectively with metallography and examination of weld metal, and the costing of welding work. Useful welding data and many mathematical and other tables are included as appendices. These combine to form a very useful book on welding, but it should be remembered that the course of instruction presented is concerned with arc welding.

To encourage the use of this book in training centres, instructional schools and large works, the publishers are willing to arrange special terms for quantities of one dozen or more ordered at one time.

Published by Philips Industrial (Philips Lamps, Ltd.), Century House, Shaftsbury Avenue, London, W.C. 2. Price, 3s. 6d.

Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. 140

THIS volume is the thirteenth of a series containing papers and discussions presented before the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers since its organisation in 1928. It contains 22 technical papers with complete discussion, and also the Howe Memorial Lecture by Dr. Charles H. Herty, jnr., and the "Round Table on Experimental Methods in the Study of Steelmaking," held in New York in February, 1939. The subjects discussed in the papers cover a very comprehensive field, and much data given will be of considerable value to those concerned with the production of iron and steel.

Four of the papers are definite contributions on the making of pig iron, and include a discussion on the thermochemical functions of the blast furnace process with a view to determining the effect on furnace efficiency of the so-called solution-loss reactions ; a study of the effect of the volume and properties of both and hearth slag on quality of iron ; the desulphurisation of pig iron with calcium carbide ; and the reduction of iron ores under pressure by carbon monoxide. Five useful papers deal with stainless steels : These include the magnetic analyses of transformations in the cold-worked 18–8 alloy ; the nature of passivity in stainless steels and other alloys in which tine-potential data are given for Cr-Ni and Cr-Ni-Mo steels ; a discussion on the pitting of stainless steels ; the effects of low-temperature heat-treatment on the elastic properties of cold-rolled austenitic stainless steels ; and the effects of temperature of pre-treatment on the creep characteristics of 18–8 stainless steel at 600° to 800° C. Several papers deal with various aspects of physical metallurgy, including an important contribution on the mechanism of austenite decomposition.

Slag control is becoming an integral part of the open-hearth activities from charge to tap, and the informative lecture by Dr. Herty, jnr., will contribute to its more extended use. Of considerable interest is the round table discussion organised by the Physical Chemistry of Steelmaking Committee of the Division. Freely discussed are such fundamentals as methods of analysis of gases and inclusions, slag-metal and gas-metal reactions, temperature measurements in molten iron and steel, methods for the study of slag compositions and characteristics, and the application of these to open hearth problems.

This volume is full of information on current problems in the iron and steel industry and on the manner in which their careful study is gradually increasing knowledge, the application of which is facilitating production or improving the quality of iron and steel. It is admirably presented and characteristic of the publications of this American Institute.

Published by the American Institute of Mining and Metallurgical Engineers, 29, West 39th Street, New York, N.Y., U.S.A.; price $5·00 net.

Methane—Its Production and Utilisation

COMMONLY known as "marsh gas" or "fire damp," methane is widely distributed throughout the earth; it is formed by bacterial action on organic matter, and is thus often to be seen rising in bubbles to the surface of stagnant ponds and marshes. It occurs in oil and coal deposits, and may be synthesised or produced from coal gas, of which it forms an important constituent. In a country depending almost entirely upon imported fuel oils and petroleum, the production and utilisation of any fuel indigenous to that country is a matter of importance, particularly in time of war. This book surveys the whole subject, and although the author directs attention more especially to the utilisation of methane gas as a fuel in internal combustion engines, applications are not confined to this outlet, but there is so little natural petroleum in Great Britain that the large unused reserves of methane gas provide a valuable alternative fuel for this purpose.

The author deals with the natural occurrence of methane, commercial production, estimated quantities, and uses. It is pointed out, for instance, that methane from coal-mine blowholes is all wasted; a colliery in Ayrshire is stated to discharge over 1,000,000 cub. ft. per day. In one year five pits in West Wales discharge nearly 1,000,000,000 cub. ft. of gas, equal to nearly 7,000,000 gals. of petrol. Private enterprise is aware to some extent of the value of these supplies, and a comprehensive scheme for their collection and use of the gas at a colliery is cited, where over 1,000,000 cub. ft. of gas are given off daily. The oil-producing countries are rich in this gas, but recent search for oil in this country has revealed that supplies of methane are available; one such source in Scotland can supply about 12,000,000 cub. ft. per day. Boreholes have been sunk for oil in various parts of the country, and the existence of considerable quantities of methane in Derbyshire and Sussex has been established; Midlothian, Yorkshire and Lancashire borings have also revealed supplies, and a new oilfield in Nottinghamshire issues many millions of cubic feet a day.

Useful information is given on the commercial production of methane from coal and coal gas, coke-oven gas, water gas, and from sewage, and an effort is made to assess the existing and potential supplies, but the author asserts that the task calls for a national survey. Much information is also given on the compression and liquefaction of the gas and on suitable containers, and brief reference is made to by-products from sewage.

In his conclusions, the author states that the known supplies of methane are at present substantial, that their development will render them vast, and that used as an alternative to petrol the actual and potential supplies can replace a large proportion of the fuel at present imported, in addition to providing a source of several important chemicals; these facts make the subject one of extreme importance to the country in peace-time as well as war-time, when the value of a home-produced fuel for transport may well be invaluable.

The author is to be commended for performing what can be regarded as a valuable service in collecting data and all relevant information to prepare this thought-provoking book; it should lead to action being taken with a view to the exploitation of methane gas.

By J. P. LAWRIE, Ph.D., F.I.C.S. Published by Messrs. Chapman and Hall, Ltd., Henrietta Street, London, W.C. 2. 66 pp. Price 6s. net.

Chrome Ore and Chromium

WITHIN recent years, chromium in its various forms has become indispensable in the arts both of peace and war, and the demand for it is ever increasing. The most important application is in alloys steels, which are widely employed in all branches of engineering; they include those commonly known as stainless and heat-resisting steels, for which chromium is an essential constituent. In addition to its importance as a source of chromium, however, the ore from which this useful metal is obtained is also largely employed in the form of bricks for the refractory linings of certain types of furnaces. It is also the raw material for the manufacture of many important chromium compounds used in various chemical industries.

All these applications are dealt with in this new volume, which has just been added to the series of monographs on mineral resources issued by the Imperial Institute. It is a book of 118 pages which, in addition to covering the utilisation of the mineral, deals with other aspects regarding its nature and occurrence, with special reference to deposits in the Empire. It is important to note, for instance, that at the present time about one-third of the ore from which chromium is produced comes from the British Empire, which possesses extensive deposits in Southern Rhodesia, the Union of South Africa, and India. The chief foreign producers are Turkey, U.S.S.R., Cuba, Philippine Islands, Yugoslavia, Greece, and New Caledonia.

The facts concerning chromium and chrome ore are presented as they were at the outbreak of war last year, and they are supported by a large number of statistical tables of production and trade. For obvious reasons no attempt has been made to modify the text in the light of subsequent events, but this monograph should be in the hands of everyone concerned with the production and use of chrome ore, and economists, teachers and the general reader will find much in it to interest and guide them. A selected list of references is given at the end of the book, which will be found invaluable for more detailed reading.

By ROBERT ALLEN, M.A., B.Sc., and G. E. Howling, B.Sc., and published by The Imperial Institute, South Kensington, London, S.W.7; price 2s. 6d. net (postage 4d.).

Bibliography of Spectrochemical Analysis

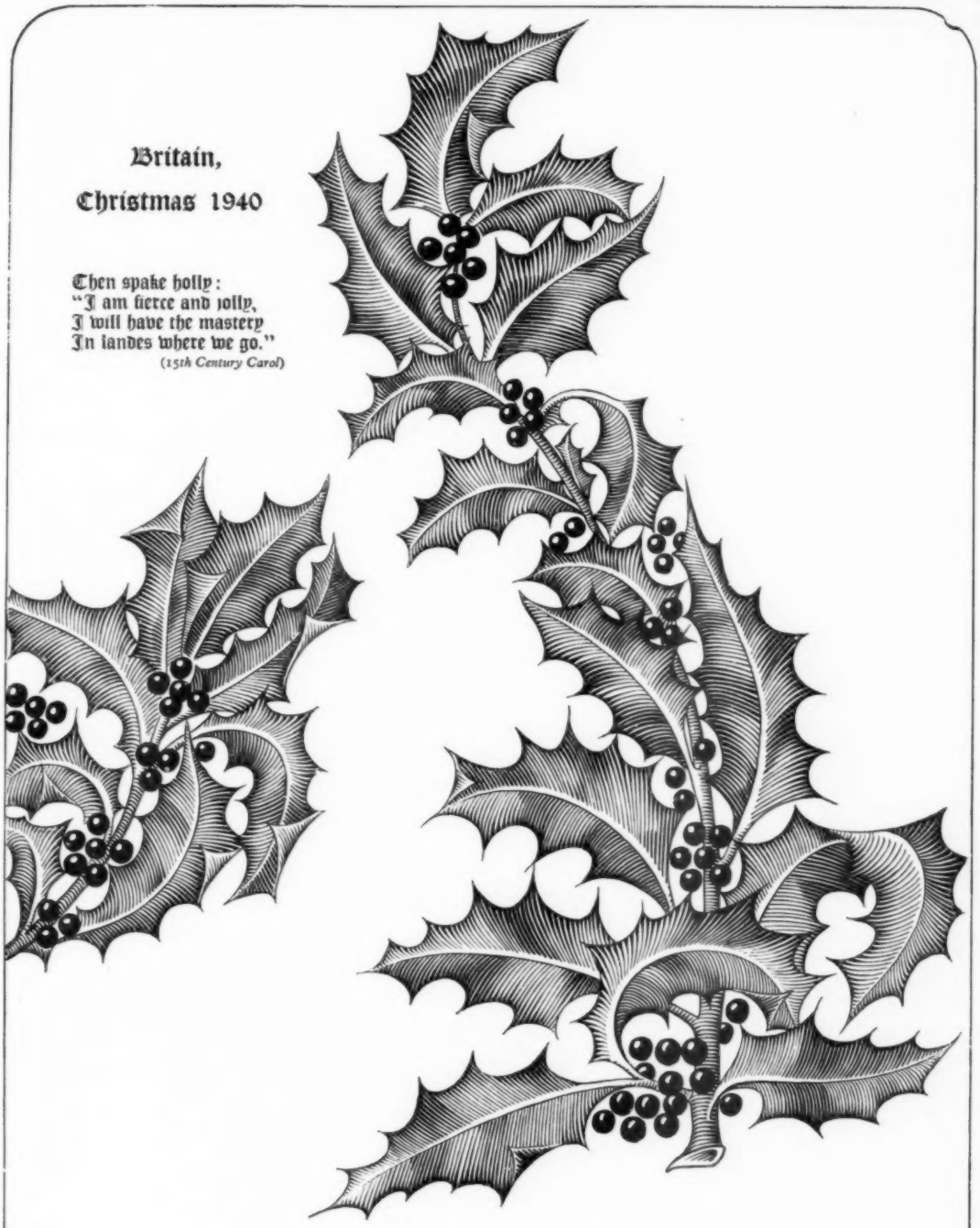
IN this bibliography are given references to books and papers of metallurgical interest, and on subjects relating thereto. The compiler's book, *Metallurgical Analysis by the Spectograph*, was published in 1933, and included a list of 114 references. This list, brought up to March, 1935, was then issued as a separate publication under the title, *Bibliography of Literature on Spectrum Analysis*. In the present second edition of the bibliography the references have been brought up to August, 1940, and now number 510. To conform with current terminology, the title has been changed.

Short explanatory notes are given with most of the references, and an author index is provided. The grouping of the references in sections obviates the necessity for a subject index. There have been some alterations to the arrangement of the matter, possibly the most important of which is the inclusion of a new section on "Applications of the Microphotometer," a subject of particular importance at the present time. As before, references are given under the headings of the individual basis metals (with cross-references) so that the reader may quickly find all the published information dealing with his particular field of interest.

Compiled by D. M. SMITH, A.R.C.S., B.Sc., D.I.C., F.Inst.P. Second edition. 55 pp. 1940. Published by the British Non-Ferrous Metals Research Association, Euston Street, London, N.W. 1. Price 3s., post free

Britain,
Christmas 1940

Then spake holly:
"I am fierce and jolly,
I will have the mastery
In landes where we go."
(15th Century Carol)



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